

SECTION 6.0

EMISSIONS OF LEAD AND LEAD COMPOUNDS FROM OTHER SOURCES

6.1 PRESSED AND BLOWN GLASS

6.1.1 Source Description

The most recent estimate available for the amount of lead used in the manufacture of glass and ceramics in the United States is from 1986. During that year, 44,960 tons (40,800 Mg) of lead were consumed.¹⁵⁶ Based on an average lead content of 28 percent for leaded glasses, an estimated 160,500 tpy (145,700 Mg/yr) of leaded glass were produced.

Adding lead to glass imparts unique qualities, including the following:

- Brilliance;
- High refractive index/high dispersion without coloring;
- Economic melting temperatures, which allows a long working range suitable to traditional methods of handworking and machining;
- High density;
- Softness, to permit cutting and decorating;
- Chemistry suitable to acid polishing; and
- High durability.¹⁵⁷

Lead glass is basically composed of silica sand and lead oxide. The lead oxide content usually ranges from 12 to 60 percent, although some types may contain as much as 92 percent lead oxide.

Lead-containing glasses are used primarily in optical glasses (such as binoculars, microscopes, telescopes), lead crystal, and cathode ray tubes for televisions, computers, and video game screens. Demand for lead for use in glass has remained stable over the past few years for most applications, with the exception of cathode ray tubes, where growth in use reflects an increased demand for video and computer terminals.¹⁵⁸ The 1992 TRI listed pressed and blown glass as the third largest category for lead air emissions. The 15 facilities reporting lead emissions in the 1992 TRI are listed in Table 6-1.¹⁵⁹

6.1.2 Process Description

The following three basic operations are performed in all leaded glass manufacturing facilities:

- Raw material preparation;
- Melting; and
- Forming.

A generic process flow diagram for leaded glass manufacturing facilities is shown in Figure 6-1.

First, raw material, including silica sand, limestone, soda ash, and litharge (PbO) are received separately at a production facility called a batch plant. The coarse materials are crushed and stored in segregated bins, transferred to a weigher, and then mixed with cullet (recycled glass) to ensure homogeneous melting. Batch weighing and mixing systems may be operated manually or may be fully automated. In preparing the high-density components for manufacturing leaded glass, most plants use high-intensity, rotating-barrel type mixers, which tumble the batch upon itself in a revolving drum or double cone. The mixture is held in a batch storage bin until it is fed to the melting furnace.

TABLE 6-1. GLASS MANUFACTURERS (SIC 3229) IN THE UNITED STATES
REPORTING LEAD AND LEAD COMPOUND EMISSIONS UNDER SARA 313

Facility	Location
Corning Asahi Video Products Co. ^a	State College, PA
Corning Inc. Fall Brook Plant	Corning, NY
Corning Inc. Stueben Plant	Corning, NY
Corning, Inc.	Danville, VA
General Electric Company	Niles, OH
GTE Products Corporation	Central Falls, RI Versailles, KY
Lancaster Glass Corporation ^b	Lancaster, OH
Lenox Crystal, Inc.	Mount Pleasant, PA
OI-NEG TV Products, Inc. ^a	Columbus, OH Perrysburg, OH Pittston, PA
Schott Glass Technologies, Inc.	Duryea, PA
St. George Crystal Ltd.	Jeannette, PA
Thomson Consumer Electronics ^a	Circleville, OH
Total	

Source: Reference 159

^a This source manufactures components for cathode ray tubes.

^b The only glass manufacturer (SIC 3229) in the 1992 TRI that reported lead compound emissions instead of lead emissions.

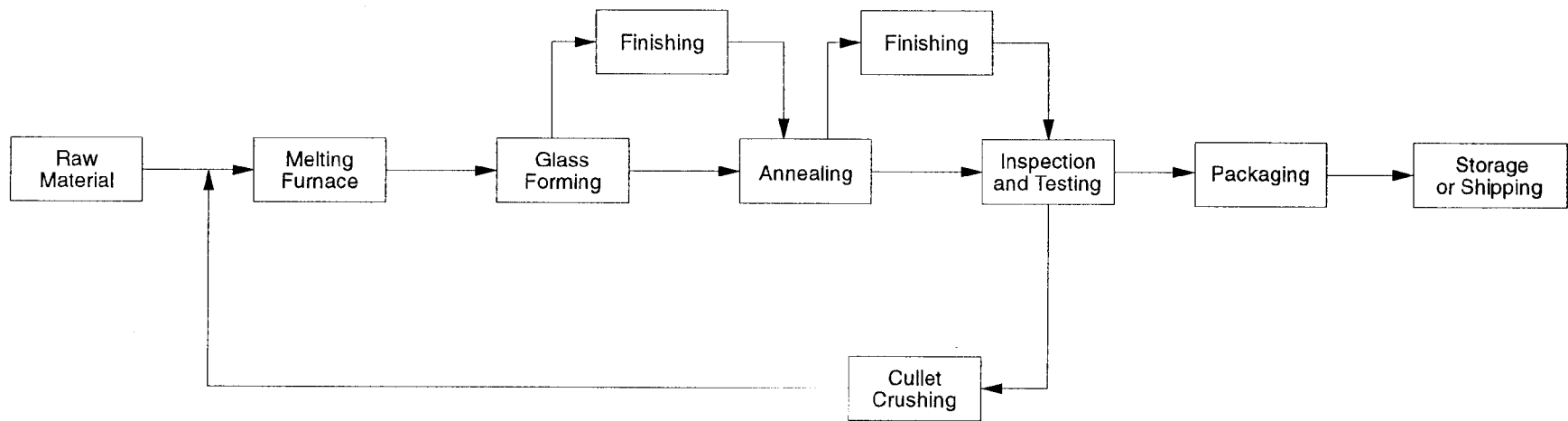


Figure 6-1. Glass Manufacturing Process

Source: Reference 160.

Next, these raw materials are melted in a melting furnace to form glass. Production of leaded glass requires heat to convert the raw material litharge to a homogeneous melt that turns to a rigid glass upon cooling. Lead that has been melted at a high temperature is introduced into the raw material, where it becomes incorporated into the glass matrix.¹⁵⁷ The glass furnaces are charged continuously or intermittently by means of manual or automatic feeders. Production of low-viscosity glass--such as crystal, which requires special production techniques--is carried out in day tanks. These tanks, usually built from refractory brick, are typically heated rapidly by one to three pairs of oil or gas burners.¹⁶¹ In addition, electric “boosting” may or may not be employed to add control over glass composition.¹⁶¹ In the furnace, the mixture of materials is held in a molten state at about 2,800°F (1,540°C) until it acquires the homogenous character of glass. It is then cooled gradually in other sections of the furnace to about 2,200°F (1,200°C) to make it viscous enough to form.

Finally, the molten material is drawn from the furnace and worked on forming machines by a variety of methods, including pressing, blowing, drawing, or rolling to produce the desired product.

The end product undergoes finishing (decorating or coating) and annealing (removing unwanted stress areas in the glass). Any damaged or undesirable glass is transferred back to the batch plant to be used as cullet.

6.1.3 Emissions

Air emissions from leaded glass manufacturing occur in three areas: raw material blending and transport, melting, and forming and finishing. Fugitive dust is produced by the blending and transport process. In most cases, fabric filters are used on silos and the transport system to confine the particulate emissions. Lead emissions from the raw material preparation and forming and finishing operations are generally considered to be negligible.

The glass melting furnace is the principal source of lead emissions from a glass plant. The main lead compounds found in the furnace discharges are lead carbonates from

gas-heated furnaces and lead sulfates from liquid fuel-fired furnaces.¹⁶² The composition and rate of emissions from glass melting furnaces vary considerably, depending upon the composition of glass being produced and, to a lesser extent, upon the design and operating characteristics of the furnace. Emissions consist primarily of products of combustion and entrained PM.

The use of fully electric furnaces is estimated to reduce lead compound emissions by a factor of 4 to 10.¹⁶² Other methods used to control emissions include:

- Use of raw materials with a lower content of fines;
- Maintenance of free moisture of the batch at about 4 to 5 percent;
- Control of the air-to-fuel ratio;
- Reduction of air flow rate on the furnace.¹⁶³

Emissions can be further reduced by lowering furnace temperature by such means as increasing broken glass ratios, modifying batch preparation, and by increasing the amount of electrical boosting.¹⁶³

If these techniques are inadequate for meeting desired emission levels, a baghouse provides the most effective means of controlling particulate emissions. Collection efficiencies have exceeded 99 percent on certain types of glass furnaces. Full-scale units are operating with filtering velocities of 1 to 2 fpm (0.5 to 1 cm/s). Precautions must be taken, however, to address problems associated with acid gases and high temperatures. SO₂ and SO₃ in the furnace exhaust may cause severe acid corrosion, and hot off-gases cause deterioration of the bag material. Bags made of felted Nomex, silicone-treated glass fiber, and Dacron have been used effectively in these applications.¹⁶³

Wet scrubbers have proven relatively ineffective in collecting submicron-size particulate that are characteristic of glass furnace emissions. Test of a low-pressure-drop wet centrifugal scrubber showed an overall efficiency of only 52 percent. Higher-energy venturi

scrubbers require a pressure drop of over 50 in. H₂O (13 kPa) to achieve an efficiency of approximately 97 percent.¹⁶³

Tests on certain glass furnaces controlled by ESPs showed efficiencies between 80 and 90 percent.¹⁶³

The composition and rate of emissions from glass melting furnaces vary considerably, depending on the composition of glass being produced and, to a large extent, on the design and operating characteristics of the furnace. Emissions consist primarily of products of combustion and entrained PM.

One emission factor for uncontrolled lead emissions from leaded glass manufacturing is presented in Table 6-2.¹⁶⁰ Based on the type of controls currently used in the glass manufacturing industry (baghouses, venturi scrubbers, ESPs), an overall control efficiency of at least 90 percent is expected.

TABLE 6-2. LEAD EMISSION FACTOR FOR GLASS MANUFACTURING

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)	Emission Factor Rating
3-05-014	All processes	Uncontrolled	5 (2.5)	B

Source: Reference 160.

6.2 LEAD-ACID BATTERY PRODUCTION

6.2.1 Source Description

Today's major use of lead is in lead-acid storage batteries. The electrical systems of vehicles, ships, and aircraft depend on such batteries for start-up and, in some cases, batteries provide the actual motive power. The battery industry is divided into two main production sectors: starting, lighting, and ignition (SLI) batteries and industrial/traction batteries.

The Battery Council International (BCI) reported a 1992 SLI battery production of 81.07 million units. This total includes both original equipment market and replacement market automotive-type batteries. Using the BCI estimate of about 18-20 lb lead per unit, the lead consumption for this sector was 768,600 tons. The industrial/traction (stationary/motive power) sector was estimated to have consumed 220,500 tons of lead.⁵⁰

There are 65 lead-acid battery manufacturing facilities in the United States.^{164,165} Table 6-3 lists these battery manufacturing facilities and their location.

6.2.2 Process Description¹⁶⁶

Figure 6-2 presents a flow diagram for lead-acid battery production. Lead-acid storage batteries are produced from lead alloy ingots and lead oxide. The lead oxide may be produced by the battery manufacturer or may be purchased from a supplier. Lead oxide is produced either by the ball mill process or the Barton process. Both processes incorporate a baghouse for product recovery and to control air emissions.

Battery manufacturing begins with grid casting and paste mixing. Battery grids are manufactured by either casting or stamping operations. In the casting operation, lead alloy ingots are charged to a melting pot; the molten lead then flows into molds that form the battery grids. These grids may be connected in a continuous strip (concast) or cast into doublets. The stamping operation consists of cutting or stamping the battery grids from lead sheets. The paste mixing operation is conducted in a batch-type process to make paste for application to the grids. A mixture of lead oxide powder, water, and sulfuric acid produces a positive paste. The negative paste is made with the same ingredients in slightly different proportions with the addition of an expander (generally a mixture of barium sulfate, carbon black, and organic fibers). Pasting machines then force these pastes into the interstices of the grids to make plates. Concast plates are then cut apart into single plates for curing in a controlled atmosphere.

TABLE 6-3. LEAD-ACID BATTERY PRODUCTION FACILITIES

Company	Location ^a
Battery Builders Inc.	Naperville, IL
C&D Charter Power Systems, Inc.	Leola, PA
	Conyers, GA
	Attica, IN
	Hugeunt, NY
Daniell Battery Mfg. Co.	Baton Rouge, LA
Douglas Battery Mfg. Co.	Winston-Salem, NC
	North Kansas City, MO
Eagle-Picher Ind. Inc.	Socorro, NM
East Penn Manufacturing Co., Inc.	Lyon Station, PA
Enpak, Inc.	Memphis, TN
Exide Corp.	Burlington, IA
	Frankfurt, IN
	Laureldale, PA
	Harrisburg, PA
	Manchester, IA
	Salina, KS
	Greer, SC
	Bristol, TN
Hawker Energy Prods. Inc.	Warrenburg, MO
GMC Delco Remy Division	Fitzgerald, GA
	Anaheim, CA
	Olathe, KS
	Muncie, IN
	New Brunswick, NJ

TABLE 6-3. LEAD-ACID BATTERY PRODUCTION FACILITIES (CONTINUED)

Company	Location ^a
GNB Inc.	City of Industry, CA
	Farmers Branch, TX
	Florence, MS
	Kankakee, IL
	Columbus, GA
	Fort Smith, AR
GNB Inc. ABD	Shreveport, LA
GNB Inc. Battery Technologies Inc.	Dunmore, PA
GNB Industrial Battery Co.	Kansas City, KS
Industrial Battery Eng.	Sun Valley, CA
Interspace/Concorde Battery Corp.	West Covina, CA ^b
Johnson Controls Battery Group, Inc.	Canby, OR
	Holland, OH
	Middletown, DE
	Geneva, IL
	Forton, CA
	Tampa, FL
	St. Joseph, MO
	Winston-Salem, NC
	Milwaukee, WI
KW Battery Co.	Skokie, IL
Power Battery Co., Inc.	Paterson, NJ
Powerflow Sys. Inc.	Terrell, TX ^b
Power Source Inc.	Ooltewah, TN ^b
Ramcar Batteries Inc.	City of Commerce, CA
Standard Ind. Inc.	San Antonio, TX ^b
Superior Battery Mfg. Co., Inc.	Russell Springs, KY

TABLE 6-3. LEAD-ACID BATTERY PRODUCTION FACILITIES (CONTINUED)

Company	Location ^a
Surrette America	Northfield, NH
Teledyne Battery Prods.	Redlands, CA
Trojan Battery Co.	Santa Fe Springs, CA
	Lithonia, GA
Universal Tool & Engineering Co.	Indianapolis, IN ^b
U.S. Battery Mfg. Inc.	Evans, GA
U.S. Battery Mfg. Co. & Battery	Corona, CA ^b
Voltmaster Co., Inc.	Corydon, IA ^b
Yuasa-Exide Inc.	Hays, KY
	Richmond, KY
	Laureldale, PA
	Sumter, SC

Source: Reference 24,164,165

^a These facilities reported lead emissions during 1993, unless otherwise noted. Lead emissions are in the form of compounds, most often lead oxides. Lead emissions are not emitted to the air as elemental lead, but they are measured as lead.

^b Facility reported emissions of lead compounds.

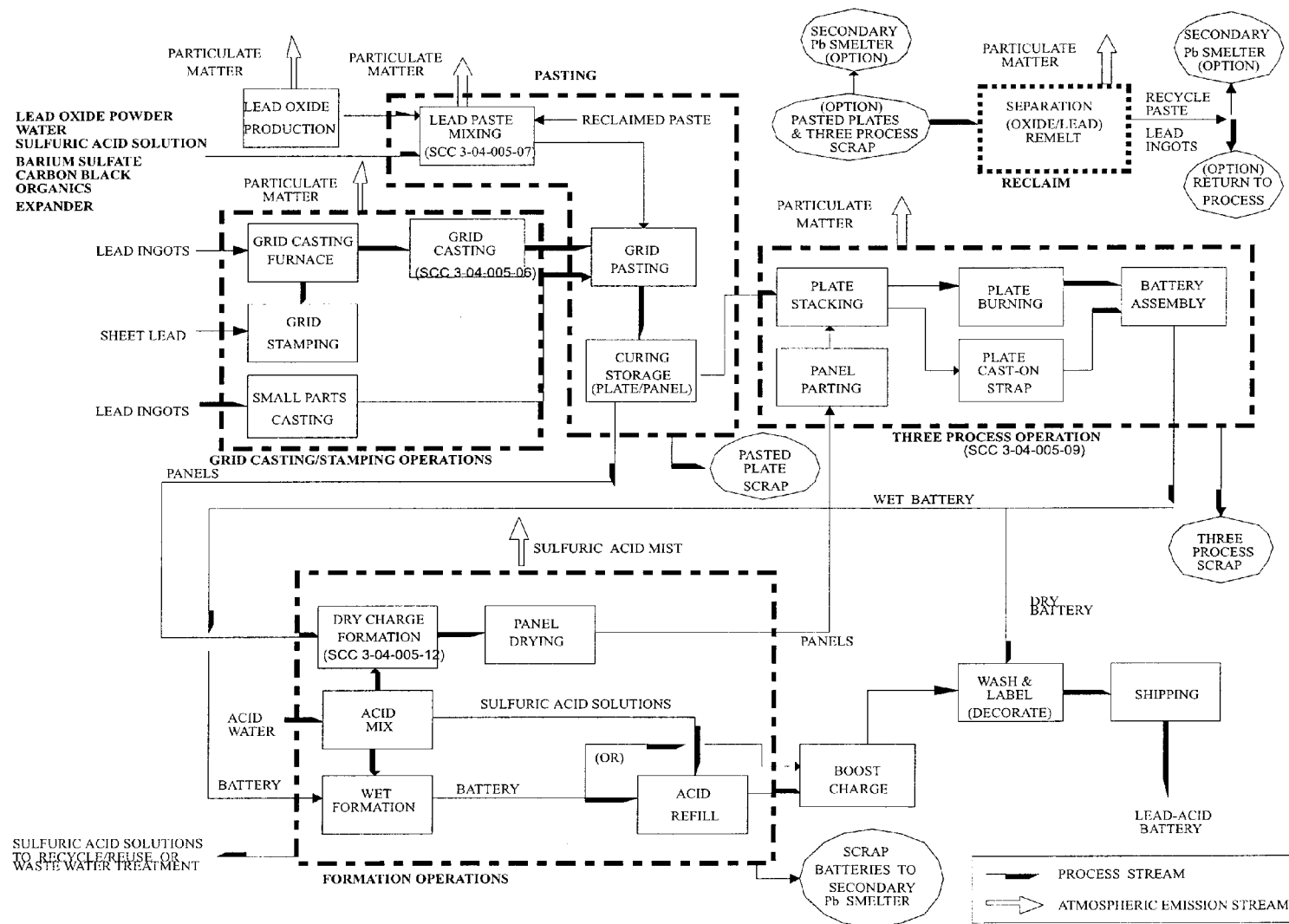


Figure 6-2. Process Flow Diagram for Lead-Acid Battery Production

Source: Reference 166.

After the plates are cured, they are sent to the three-process operation of plate stacking, plate burning, and element assembly into the battery case. In this operation, the doublet plates are first cut apart and, depending on whether they are dry-charged or to be wet-formed, they are stacked in an alternating positive and negative block formation with insulators between them. These insulators are made of non-conductive materials such as plastic or glass fiber. During the burning operation, leads are welded to tabs on each positive or negative plate, fastening the assembly (element) together. An alternative to this operation is the cast-on strap connection, where molten lead is poured around and between the plate tabs to form the connection. Then a positive tab and negative tab are independently welded to produce an element. The completed elements are then automatically placed into battery cases either before formation (wet batteries) or after formation (dry batteries). A top is placed on the battery case. The posts on the case top are welded to two individual points that connect the positive and negative plates to the positive and negative posts, respectively.

During formation, the inactive lead oxide-sulfate paste is chemically converted into an active electrode. Lead oxide in the positive plates is oxidized to lead peroxide; in the negative plates it is reduced to metallic lead. The unformed plates are placed in a dilute sulfuric acid solution. The positive plates are connected to the positive pole of a direct current (dc) source and the negative plates are connected to the negative pole of the dc source. In the wet formation process, the elements are assembled into the battery case before forming. After forming, the spent acid may be dumped and fresh acid added, and a boost charge is added to complete the battery. In the dry formation process, the individual plates may be assembled into elements first, and then formed in large tanks of sulfuric acid or formed as individual plates. The formed elements from either method are placed in the battery cases, the positive and negative parts of the elements are connected to the positive and negative terminals of the battery, and the batteries are shipped dry.

Defective parts are either reclaimed at the battery plant or are sent to a secondary lead smelter for recycling. Lead reclamation facilities at battery plants are generally pot-type furnaces for non-oxidized lead. Approximately 1 to 4 percent of the lead processed at a typical lead-acid battery plant is recycled through reclamation as paste or metal.

Lead oxide emissions result from the discharge of air used in the lead oxide production process. Fabric filtration is generally used as part of the process control equipment to collect particulate emissions from lead oxide facilities.

Lead and other particulate matter are generated in several operations within storage battery production, including grid casting, lead reclamation, slitting, small parts casting, and during the three-process operation. These particulates are usually collected by ventilation systems and ducted through fabric filters (baghouses).

Significant emissions of lead oxide may result during the first step of the paste mixing operation when dry ingredients are charged to the mixer. These emissions are usually collected and ducted through a baghouse (or impingement wet scrubber). Also, during the second step, when moisture is present in the exhaust stream from acid addition, emissions from the paste mixer are generally collected and ducted to either an impingement scrubber or fabric filter. Emissions from grid casting machines, lead reclamation facilities, and the three-process operation are sometimes processed by impingement wet scrubbers, but normally through a baghouse.

Sulfuric acid mist emissions are generated during the formation operation. These emissions are significantly higher for dry formation processes than for wet formation processes because wet formation takes place in battery cases and dry formation is conducted in open tanks (a practice which is decreasing within the industry). Wet formation processes usually do not require control. Emissions of sulfuric acid mist from dry formation processes can be reduced by more than 95 percent by the use of mist eliminators or scrubbers. Also, acid mist emissions from dry formation are commonly controlled by the application of surface foaming agents over the acid baths or receptacles. Other emission control practices are water sprays and good work practices in general.

Emission reductions of 99 percent and above can be obtained when fabric filters are used to control slitting, paste mixing, and three-process operations. The use of scrubbers to

control emissions from paste mixing and grid casting operations, and at lead reclamation facilities, can result in emissions reductions of 85 percent or better.

Many lead-acid battery manufacturing plants use central vacuum systems for general housekeeping practices. However, these units may be subject to the New Source Performance Standards (NSPS) for lead-acid battery manufacture as an “other lead emitting source.” The industry typically uses fabric filters to control exhaust emissions from these vacuum systems.

Fabric filters have become an accepted method for controlling emissions from grid casting and lead reclamation. Also, since the original NSPS development project, two new lead control techniques have been applied to various facilities manufacturing lead-acid batteries. These are the use of cartridge collectors as primary control devices and the use of high efficiency particulate air (HEPA) filters for secondary collection. Specifically, cartridge collectors and HEPA filters can be used in grid casting, paste mixing, lead oxide manufacturing, the three-process operation, or lead reclamation.

Table 6-4 presents lead emission factors for lead-acid battery manufacturing operations and lead oxide production. The emission factors presented include lead and its compounds, expressed as elemental lead. Controlled emission factors expressed in terms of lead emissions per lead processed or production were not readily available. Therefore, the appropriate control efficiency should be applied to the uncontrolled factors. Bag filters and scrubbers are the most commonly used controls for lead acid batteries.²⁴ Emissions data for lead-acid battery manufacturing facilities, including grid casting, paste mixing, lead oxide manufacturing, three-process operation, lead reclamation, and formation are presented in the EPA document *Review of New Source Performance Standards for Lead-Acid Battery Manufacture*.¹⁶⁵

TABLE 6-4. LEAD EMISSION FACTORS FOR LEAD-ACID BATTERY PRODUCTION

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/1000 batteries (kg/1000 batteries) ^a	Emission Factor Range in lb/1000 batteries (kg/1000 batteries) ^a	Emission Factor Rating	Reference
3-04-005-05	Total Production	None	---	1.53x10 ⁻¹ - 1.77x10 ⁻¹ (6.95 - 8.05)	U	166
3-04-005-06	Grid Casting	None	---	7.70x10 ⁻¹ - 9.00x10 ⁻¹ (3.50x10 ⁻¹ - 4.09x10 ⁻¹)	B	166
		Rotoclone	6.73x10 ⁻² (3.06x10 ⁻²)	6.10x10 ⁻² - 8.00x10 ⁻² (2.77x10 ⁻² - 3.64x10 ⁻²)	U	92
3-04-005-07	Paste Mixing	None	---	1.10 - 2.49 (5.00x10 ⁻¹ - 1.13)	B	166
		Wet Scrubber - Medium Efficiency	4.00x10 ⁻⁴ (2.00x10 ⁻⁴) ^b	---	U	22
3-04-005-08	Lead Oxide Mill (Baghouse Outlet)	FF	---	1.10x10 ⁻¹ - 1.20x10 ⁻¹ (5.00x10 ⁻² - 5.50x10 ⁻²)	C	166
3-04-005-09	Three-process Operation	None	---	1.06x10 ⁻¹ - 1.46x10 ⁻¹ (4.82 - 6.64)	B	166
		FF	3.77x10 ⁻¹ (1.71x10 ⁻¹)	2.40x10 ⁻¹ - 4.59x10 ⁻¹ (1.09x10 ⁻¹ - 2.09x10 ⁻¹)	U	92
3-04-005-10	Lead Reclaiming Furnace	None	---	7.70x10 ⁻¹ - 1.38 (3.50x10 ⁻¹ - 6.27x10 ⁻¹)	B	166
		Scrubber	1.01x10 ⁻¹ (5.05x10 ⁻²) ^b	6.40x10 ⁻² - 1.42x10 ⁻¹ (3.20x10 ⁻² - 7.10x10 ⁻²) ^b	U	168
3-04-005-11	Small Parts Casting	None	1.00x10 ⁻¹ (4.60x10 ⁻²)	---	C	166
3-04-005-12	Formation	None	---	---		166

^a Emission factors are expressed in lb (kg) of lead emitted per 1000 batteries produced, except where noted.

^b Emission factors are expressed in lb (kg) of lead emitted per ton (Mg) of lead produced.

"---" means data are not available.

6.3 LEAD OXIDES IN PIGMENTS

Lead oxide is used primarily in the manufacture of lead-acid storage batteries (see Section 6.2). It is also useful as a pigment in paints and ceramic glazes. The principal oxides of lead include litharge, lead dioxide, and red lead. Black oxide, the most widely used form of lead oxide, consists of a mixture of litharge and finely divided metallic lead. Red lead is a major lead pigment. Other lead pigments include white lead, lead chromates, and leaded zinc oxides. Total lead oxide production in the United States in 1995 was 68,013 tons, excluding lead oxide used in batteries (61,700 Mg).¹⁶⁷

6.3.1 Source Location

The distribution of facilities manufacturing lead oxides in lead pigments in the United States is presented in Table 6-5.

6.3.2 Process Description

Lead Oxides

Lead Monoxide--Most lead oxides and many of the major lead pigments are derived from lead monoxide, in a form called litharge. There are four principal processes for producing high-grade litharge:

- Metallic lead is partially oxidized and milled to a powder, which is charged into a reverberatory furnace at about 1,100°F (590°C) to complete the oxidation to ordinary “chemical litharge;”
- Pig lead is oxidized and stirred in a reverberatory furnace or rotary kiln to form lead monoxide;
- Molten lead is run into a cupelling furnace held at about 1,800°F (1,020°C), and molten litharge is produced; and
- Molten lead at about 950°F (510°C) is atomized into a flame where it burns vigorously, producing “sublimed” or “fumed” litharge.

TABLE 6-5. U.S. FACILITIES MANUFACTURING LEAD OXIDES IN PIGMENTS

<u>Lead Oxides</u>	
Lead Monoxide	
Admiral Chemical Co.	Peabody, Massachusetts
ASARCO Incorporated	Denver, Colorado
Eagle-Picher Industries, Inc., Electronics Division, Chemicals Department	Joplin, Missouri
Great Western Inorganics	Golden, Colorado
Hammond Lead Products, Inc.	Hammond, Indiana Pottstown, Pennsylvania
Johnson Matthey, Inc., Aesar/Alfa	Wardhill, Massachusetts
Micron Metals, Inc., Atlantic Equipment Engineers Division	Bergenfield, New Jersey
Oxide & Chemical Corporation	Brazil, Indiana Lancaster, Ohio
Pacific Dunlap	Columbus, Georgia
Quenell Enterprises, Inc., Daelco Division	City of Commerce, California
Lead Dioxide	
Aithaca Chemical Corporation	Uniondale, New York
Eagle-Picher Industries, Inc., Electronics Division, Chemicals Department	Joplin, Missouri
Hammond Croton, Inc.	South Plainfield, New Jersey
PSI Chemicals Division, Pluess & Stauffer International, Inc.	Stamford, Connecticut
Spectrum Chemical Manufacturing Corporation	Gardena, California
<u>Lead Pigments</u>	
Red Lead	
Hammond Lead Products, Inc.	Hammond, Indiana Pottstown, Pennsylvania
Oxide & Chemical Corporation	Brazil, Indiana
Spectrum Chemical Manufacturing Company	Gardena, California
Robert I. Webber Co., Inc.	City of Commerce, California Stamford, Connecticut
White Lead	
Hammond Lead Products, Inc., Halstab Division	Hammond, Indiana
National Chemical Co., Inc.	Chicago, Illinois

TABLE 6-5. U.S. FACILITIES MANUFACTURING LEAD OXIDES IN PIGMENTS
(CONTINUED)

Lead Chromate	
Aithaca Chemical Corporation	Uniondale, New York
ALL-Chemic, Ltd.	Fort Lee, New Jersey
Cookson Pigments, Inc.	Newark, New Jersey
Engelhard Corporation, Pigments and Additives Division	Louisville, Kentucky
Kikuchi Color & Chemicals Corp. U.S.A.	Paterson, New Jersey
Mineral Pigments Corporation, Chemical Color Division	Beltsville, Maryland
National Chemical Co., Inc.	Chicago, Illinois
Spectrum Chemical Manufacturing Company	Gardena, California
Wayne Pigment Corporation	Milwaukee, Wisconsin
Lead Antimonate Yellow Pyrochlore	
Ferro Corporation, Coatings, Colors & Electronic Materials Group, Color Division	Cleveland, Ohio

Source: References 169,170,171

In all cases, the product must be cooled quickly to below 570°F (300°C) to avoid formation of red lead.¹⁶³

Black Oxides--Black oxide typically contains 60 to 80 percent litharge and 20 to 40 percent finely divided metallic lead. It is used exclusively in the manufacture of lead-acid storage batteries, specifically in the production of battery paste. It is usually produced by the Barton process, but is also produced by the ball mill process. In both processes, a baghouse is used for product recovery.

The Barton process is shown in Figure 6-3. Lead ingots are first melted and then fed into a vessel or pot, where the molten lead is rapidly stirred and atomized into small droplets. The droplets of molten lead are then oxidized by air drawn through the pot and conveyed to a product recovery system, which typically consists of a settling chamber, cyclone, and baghouse.

In the ball mill process, shown in Figure 6-4, lead pigs or ingots are charged with air into a ball mill. Oxidation is initiated by the heat generated by the tumbling lead ingots. During milling, the lead oxide that forms on the surface of the ingots and fine particles of unoxidized lead are broken off, forming a fine dust that is removed from the mill by a circulating air stream. Air flow through the mill, the temperature of the charge, and the weight of the charge are controlled to produce a specified ratio of lead oxide to finely divided metallic lead. Centrifugal mills and/or cyclones are used to collect large particles, while the finer particles are collected in a baghouse.

Lead Dioxide--Lead dioxide is a vigorous oxidizing agent used in a number of chemical process industries. It decomposes to lower oxides rather easily, releasing oxygen. It is commercially produced either by the treatment of an alkaline red lead slurry with chlorine, or by anodic oxidation of solutions of lead salts. The amount of lead dioxide produced is insignificant and of little commercial importance.¹⁶³

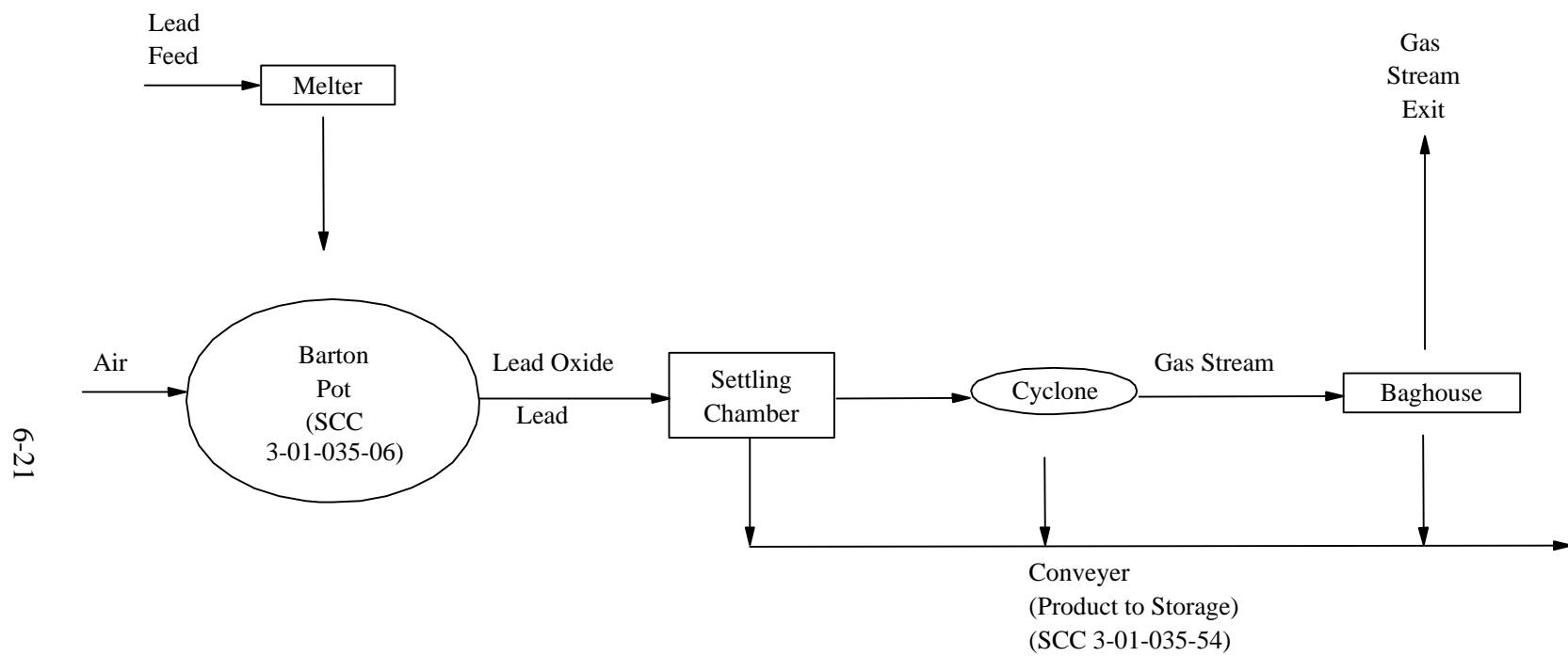


Figure 6-3. Barton Pot Process for Lead Oxide Manufacture

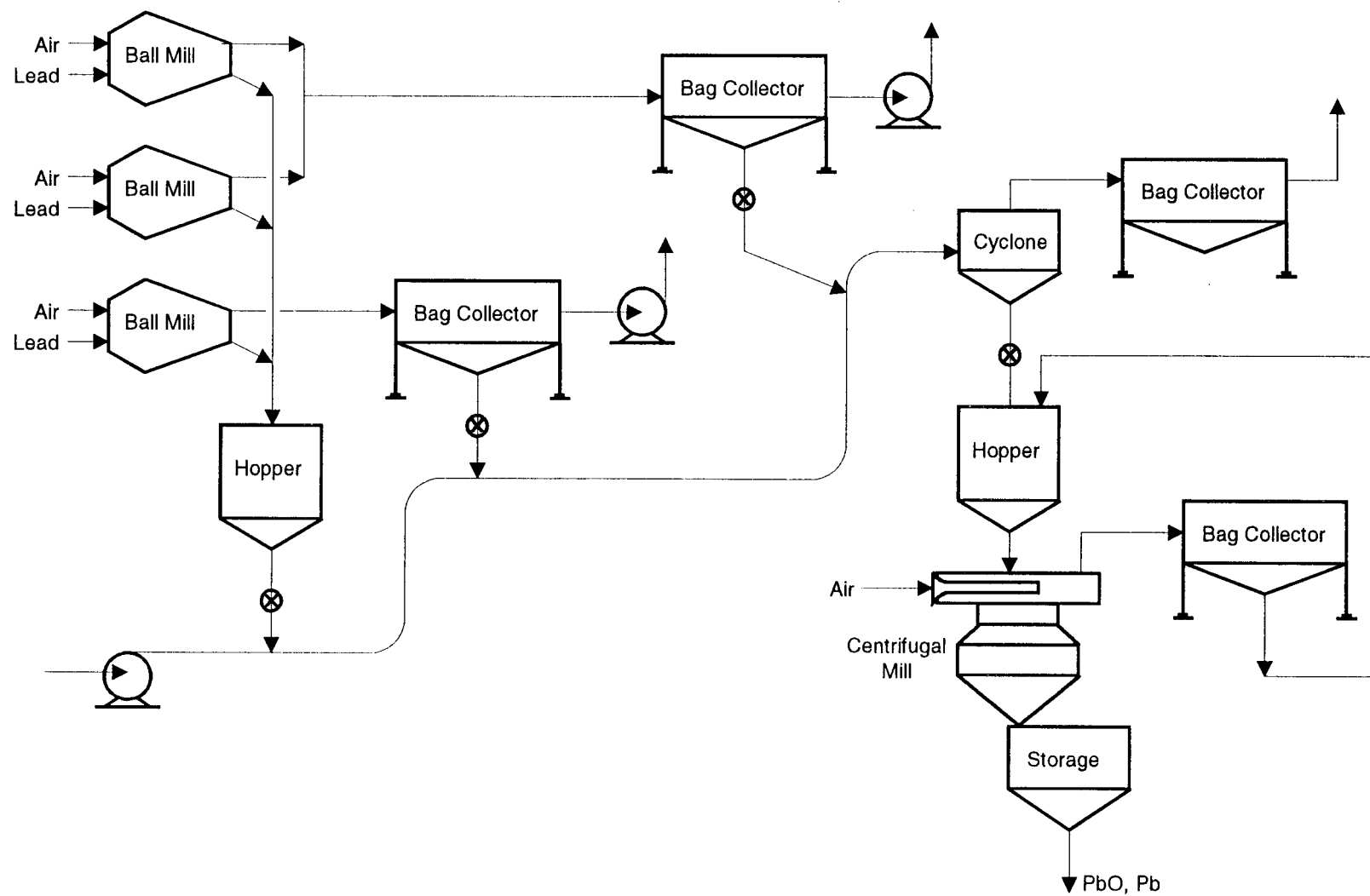


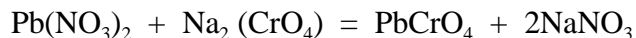
Figure 6-4. Ball Mill Process for Lead Oxide Manufacture

Lead Pigments

Red Lead--Red lead, also called minium, is used principally in ferrous metal protective paints. The manufacture of red lead begins by charging litharge into a reverberatory furnace held at 900 to 950°F (480 to 510°C). The litharge is oxidized until a specified amount of lead monoxide is converted to Pb_3O_4 . A typical red lead manufacturing plant will produce 30 tons (27 Mg) of red lead per day.

White Lead--The commercial varieties of white lead include basic carbonate white lead, basic sulfate white lead, and basic lead silicate. Manufacture of basic carbonate white lead is based on the reaction of litharge with acetic acid. The product of this reaction is then reacted with carbon dioxide to form lead carbonate, which is contained in a slurry and recovered by wet filtration and drying. Other white leads are made either by a chemical or a fuming process. The chemical process is like that described above except that other mineral dioxides are used in place of carbon dioxide. The fuming process differs in that the product is collected in a baghouse rather than by wet slurry filtration and drying.

Lead Chromate--Chromate pigments are generally manufactured by precipitation or calcination. A commonly used process is the reaction of lead nitrate solution with sodium chromate solution:



The lead nitrate solution can be made using either lead monoxide or by reacting molten lead with nitric acid.

Leaded Zinc Oxides--Leaded zinc oxides are used almost entirely as white pigments for exterior oil-base paints. Leaded zinc oxides are produced either by smelting and cofuming combinations of zinc and lead sulfide ores or by mechanically blending separately

prepared fractions of zinc oxide and basic lead sulfate. The first process involves heating the two materials to produce a fume, which is cooled and collected in a baghouse.

6.3.3 Emissions

Lead Oxides

Exhaust gas characteristics typical of those associated with the manufacture of litharge and black oxide, using the ball mill and Barton processes, are summarized in Table 6-6. Based on an average lead emission rate of 0.44 lb/ton (0.22 g/kg) product and consumption of 65,600 tons (59,600 Mg) of lead for other oxides, an estimated 14 tons (13 Mg) of lead was emitted into the atmosphere by lead oxide production facilities (other than storage battery production) in 1991.¹⁷²

Lead Pigments

Red Lead--Collection of dust and fume emissions from the production of red lead is an economic necessity. Consequently, particulate emissions are minimal. Particulate emissions after a baghouse have been measured at 1.0 lb/ton (0.5 g/kg) product.¹⁶³ Only lead monoxide and oxygen go into the production of red lead, so most of the particulate emissions can be assumed to be lead.

Data on emissions from the production of white lead pigments, leaded zinc oxides, and chrome pigments are not available.

Baghouses, usually preceded by dry cyclones or settling chambers, are the universal choice for the recovery of lead oxides and most pigments. The baghouses used are generally mechanical shaker types, and are operated at air-to-cloth ratios ranging from 1 to 3 fpm (0.5 to 1.5 cm/s). Other types, including pulse jet units, have also been used. Dry cyclones and/or settling chambers are usually installed upstream of the baghouse to capture larger particles and provide cooling. Performance data on several baghouse installations servicing lead oxide

TABLE 6-6. CHARACTERISTICS OF UNCONTROLLED EXHAUST GAS FROM LEAD OXIDE BALL MILL AND BARTON POT PROCESSES

Parameters	English Units	Standard International Units
Gas flow rate	2,300 acfm/tph Pb charged	1.2 m ³ /s.Mg.h ⁻¹ Pb charged
Temperature	250°F	120°C
Grain loading	3 to 5 gr/scf	7 to 11 g/m ³
Particle size distribution, wt%	0 to 1 µm - 4%	4%
	1 to 2 µm - 11%	11%
	2 to 3 µm - 23%	23%
Lead emission factor ^a	0.44 lb/ton product	0.22 g/kg product

Source: Reference 173

^a Emissions are after a baghouse, which is considered process equipment.

production facilities are presented in Table 6-7. Collection efficiencies in excess of 99 percent are generally considered achievable.

Lead emission factors found in the literature for the manufacture of lead oxides and lead pigments are presented in Table 6-8. The emission factors for lead oxide production were assigned an E rating because of high variabilities in test run results and nonisokinetic sampling.

6.4 LEAD CABLE COATING

6.4.1 Source Description

About 90 percent of the lead cable covering produced in the United States is on lead-cured jacketed cables and 10 percent is on lead-sheathed cables.¹⁷⁴ Approximately 7,000 tons of lead were consumed for lead cable sheathing production in 1996.¹⁷⁵ Today, lead sheathing is only being used on power cables with voltage levels generally greater than 10 kV.

TABLE 6-7. PERFORMANCE TEST RESULTS ON BAGHOUSES SERVING LEAD
OXIDE FACILITIES

	Barton Pot	Hammermill Furnace	Hammermill Furnace
Control system	Settling chamber/ cyclone/baghouse	Cyclone/baghouse	Cyclone/baghouse
Test point	Outlet	Outlet	Inlet
Particulate emissions:			
gr/dscf	0.032 - 0.056	0.012	32.9
g/m ³	0.074 - 0.13	0.028	75.7
lb/ton product	0.41 - 0.85	0.057	
gr/kg product	0.21 - 0.43	0.028	
Lead emissions:			
gr/dscf	0.024 - 0.046	0.008	30.3
g/m ³	0.055 - 0.11	0.018	69.7
lb/ton product	0.30 - 0.69	0.042	
gr/kg product	0.15 - 0.35	0.021	

Source: Reference 173

TABLE 6-8. LEAD EMISSION FACTORS FOR MANUFACTURE OF LEAD OXIDE IN PIGMENTS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg) ^a	Emission Factor Rating
Lead Oxide Production				
3-01-035-06	Barton pot	None	4.40x10 ⁻¹ (2.20x10 ⁻¹)	E
3-01-035-07	Calciner	None	1.40x10 ¹ (7.0)	E
		Baghouse	5.00x10 ⁻² (2.50x10 ⁻²)	E
Pigment Production				
3-01-035-10	Red Lead	None	9.00x10 ⁻¹ (4.50x10 ⁻¹)	B
3-01-035-15	White Lead	None	5.50x10 ⁻¹ (2.75x10 ⁻¹)	B
3-01-035-20	Lead Chromate	None	1.30x10 ⁻¹ (6.50x10 ⁻²)	B

Source: Reference 12

^a Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of oxide/pigment produced.

6.4.2 Process Description

The manufacture of cured jacketed cables involves a stripping/remelt operation because an unalloyed lead cover that is applied in the vulcanizing treatment during the manufacture of rubber-insulated cable must be stripped from the cable and remelted. Lead coverings are applied to insulated cable by hydraulic or screw-type presses. Molten lead is continuously fed into the press, where it solidifies as it is extruded onto a cable.¹⁷⁴ Continuous extruders are the most prevalent means of producing lead-sheathed power cable. Continuous extruders have largely replaced the ramp-press equipment widely used prior to 1950.¹⁷⁶

Extrusion rates for typical presses are 3,000 to 15,000 lb/hr (1.3 to 6.8 Mg/hr). A lead melting kettle supplies lead to the press, which is heated either electrically or with a combustion-type burner.

6.4.3 Emissions

The melting kettle is the only source of atmospheric lead emissions in lead sheathing production. Fumes from these kettles are exhausted to the atmosphere. Table 6-9 presents uncontrolled lead emission factors for cable covering.

Cable sheath reliability and quality relate directly to the oxide content of the sheath. Because of lead density, flotation of lead oxides from the melting and holding kettles used to feed the extruder is possible. To minimize introduction of oxygen into the lead bath, modern melting pots use pneumatically operated lids and splash prevention devices on the ingot loading mechanism.¹⁷⁶

Further control is provided by controlling the height of the overflow channel from the melting pot to the holding pot by properly spacing the baffles to prevent oxide movement along the direction of metal flow and bottom tapping of the holding pot.¹⁷⁶

Emissions data from facilities with any type of emission controls are scarce or unavailable. Also, the percentage of facilities having any type of controls in place is unknown.

Cable covering processes do not usually include particulate collection devices. However, fabric filters, scrubbers, or cyclones can be installed to reduce lead emissions at different control efficiency levels. Process modifications to minimize emissions include lowering and controlling the melt temperature, enclosing the melting unit, and using fluxes to provide a cover on the melt.

TABLE 6-9. LEAD EMISSION FACTOR FOR LEAD CABLE COATING

SCC Number	Process/Emission Source	Control Device	Average Emission Factor lb/ton (kg/Mg) ^a	Emission Factor Range lb/ton (kg/Mg) ^a	Emission Factor Rating
3-04-040-01	Cable Covering	None	5.00x10 ⁻¹ (2.50x10 ⁻¹)	---	C

Source: Reference 57,174

^a Emission factors are expressed in lb (kg) of lead emitted per ton (Mg) lead processed.

"---" means data are not available.

Frit is a homogeneous melted mixture of inorganic materials that is used in enameling iron and steel and in glazing porcelain and pottery. Frit renders soluble and hazardous compounds (such as lead) inert by combining them with silica and other oxides. Frit also is used in bonding grinding wheels, to lower vitrification temperatures, and as a lubricant in steel casting and metal extrusion.¹⁷⁷

6.5.1 Process Description

Frit is prepared by fusing a variety of minerals in a furnace and then rapidly quenching the molten material. The constituents of the feed material depend on whether the frit is to be used as a ground coat or as a cover coat. For cover coats, the primary constituents of the raw material charge include silica, fluorspar, soda ash, borax, feldspar, zircon, aluminum oxide, lithium carbonate, magnesium carbonate, and titanium oxide. The constituents of the charge for a ground coat include the same compounds plus smaller amounts of metal oxides such as cobalt oxide, nickel oxide, copper oxide, and manganese oxide.¹⁷⁷

To begin the process, raw materials are shipped to the manufacturing facility by truck or rail and are stored in bins. Next, the raw materials are carefully weighed in the correct proportions. The raw batch is then dry mixed and transferred to a hopper prior to being fed into the smelting furnace. Although pot furnaces, hearth furnaces, and rotary furnaces have been used to produce frit in batch operations, most frit is now produced in continuous smelting furnaces. Depending on the application, frit smelting furnaces operate at temperatures of 1700° to 2700°F (930° to 1480°C). If a continuous furnace is used, the mixed charge is fed by screw conveyor directly into the furnace. Continuous furnaces operate at temperatures of 2000° to 2600°F (1090° to 1430°C). When smelting is complete, the molten material is passed between water-cooled metal rollers that limit the thickness of the material, and then it is quenched with a water spray that shatters the material into small glass particles called frit.¹⁷⁷

After quenching, the frit is milled by either wet or dry grinding. If the latter, the frit is dried before grinding. Frit produced in continuous furnaces generally can be ground without drying, and it is sometimes packaged for shipping without further processing. Wet milling of frit is no longer common. However, if the frit is wet-milled, it can be charged directly to the grinding mill without drying. Rotary dryers are the devices most commonly used for drying frit. Drying tables and stationary dryers also have been used. After drying, magnetic separation may be used to remove iron-bearing material. The frit is finely ground in a ball mill, into which clays and other electrolytes may be added, and then the product is screened and stored. The frit product then is transported to on-site ceramic manufacturing processes or is prepared for shipping. In recent years, the electrostatic deposition spray method has become the preferred method of applying frit glaze to surfaces. Frit that is to be applied in that manner is mixed during the grinding step with an organic silicon encapsulating agent, rather than with clay and electrolytes. Glaze application to ceramics is discussed in more detail in Section 6.6. Figure 6-5 presents a process flow diagram for frit manufacturing.¹⁷⁷

6.5.2 Emissions

When frit containing lead oxides is being manufactured, lead emissions are created by the frit smelting operation in the form of dust and fumes. These emissions consist primarily of condensed lead oxide fumes that have volatilized from the molten charge.¹⁷⁷

Lead emissions from the furnace can be minimized by careful control of the rate and duration of raw material heating, to prevent volatilization of the more fusible charge materials. Lead emissions from rotary furnaces also can be reduced with careful control of the rotation speed, to prevent excessive dust carryover. Venturi scrubbers and fabric filters are the devices most commonly used to control emissions from frit smelting furnaces, and fabric filters are commonly used to control emissions from grinding operations. No information is available on the type of emission controls used on quenching, drying, and materials handling and transfer operations.¹⁷⁷ Also, no lead emission factors for frit manufacturing were identified.

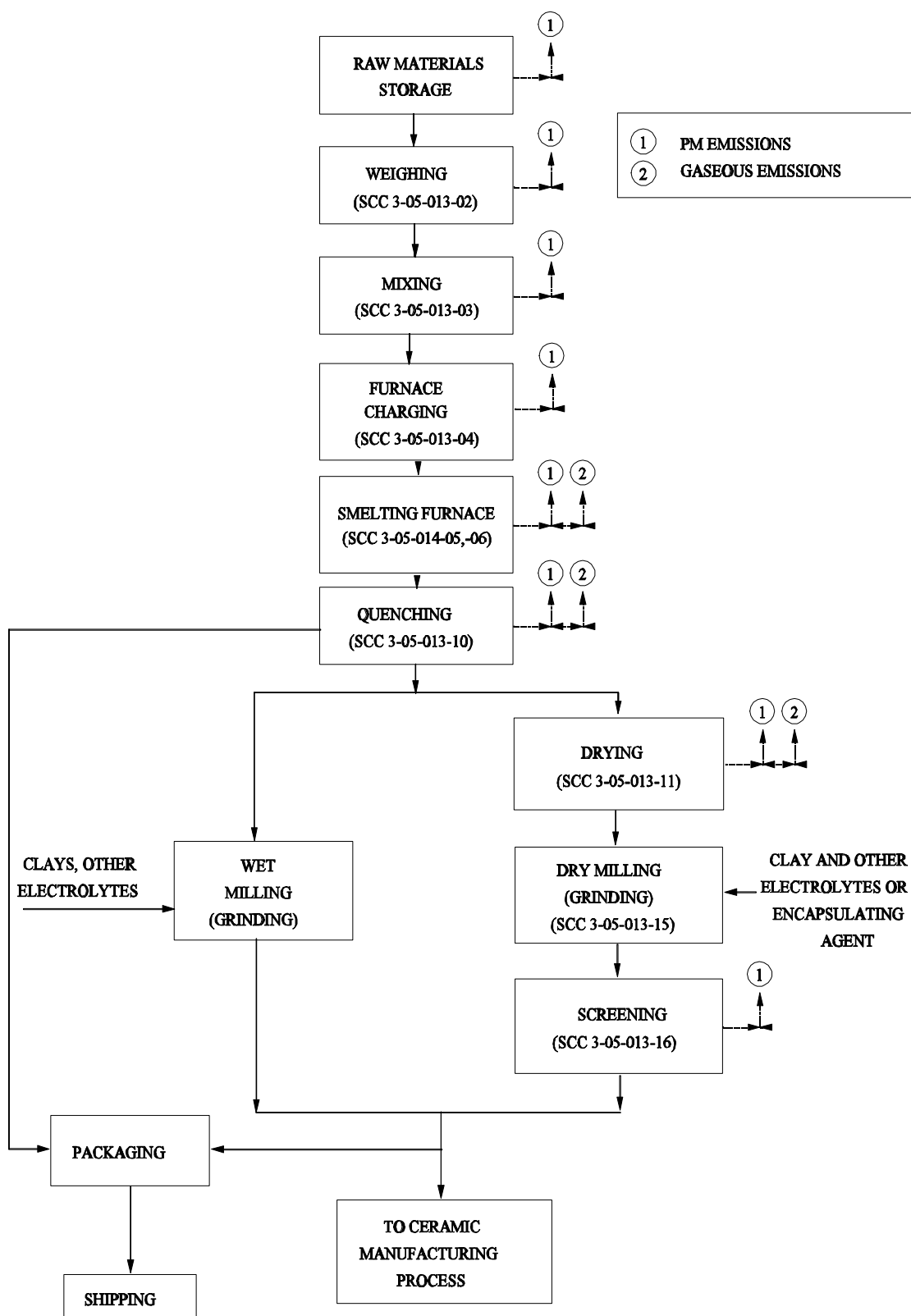


Figure 6-5. Process Flow Diagram for Frit Manufacturing

Glazes are applied to clay-based ceramic products to provide a shiny, generally smooth surface and to seal the clay.¹⁷⁸ Adding lead to glazes dramatically improves their chemical durability and heightens color, helping them to withstand detergent attack. Lead gives a smooth, durable hygienic surface that resists scratching. Lead also allows the glaze to be melted and fluxed easily. Lead increases the strength of the bond between glaze and substrate.¹⁷⁹

Basic carbonate white lead [$2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$] has been the preferred leaded glaze used in ceramic manufacture for hundreds of years. White lead has varied applications in whiteware glazes, particularly for fine china and commercial artware. White lead has a small particle size and lower particle density, making it capable of suspending a glaze without the presence of clays or organic binders. However, white lead and other lead oxides are more soluble than other forms of lead, and because the lead leaches out over time, they are being phased out by the ceramic industry.¹⁴

The ceramics industry is addressing this solubility problem by adding lead to glaze in frit form. The frit is a ground mixture of two or more compounds. For example, lead monosilicate ($\text{PbO} \cdot 0.67\text{SiO}_2$), which is considered one of the most economical methods for introducing lead into a glaze, contains 85 percent PbO and 15 percent SiO_2 . The frit form desolubilizes and detoxifies the lead compounds. The frit also allows the glazes to be fired at lower temperatures and creates a more uniform glaze. The fritted glaze usually includes clay or organic binders, which ensure that the glaze adheres to the ceramic and does not dust off prior to firing.¹⁴ Frits are usually manufactured by frit manufacturers rather than ceramic manufacturers. (See Section 6.3 for a list of frit manufacturers.)

Since the 1970s, attention has been focused on the use of lead glazes in china dishes and the tendency for lead from the glaze to leach into food. This tendency toward leachability depends upon several factors, including glaze composition, firing conditions, pH (e.g., orange, tomato juices, vinegar), temperature, and physical state of food (liquid, moist), duration of food contact.

The following presents a brief history of the regulatory drivers influencing lead reduction in ceramics. The U.S. Food and Drug Administration (FDA) set informal guidelines in 1971 for levels of lead leaching from ceramic products. These levels were tightened in 1979. They are now being further reduced because new information shows that lead can pose health hazards. The guideline levels for lead leaching from ceramic waste are being reduced as follows:

- From 7.0 to 3.0 ppm for plates, saucers, and other flatware;
- From 5.0 to 2.0 ppm for small hollowware, such as cereal bowls (but not cups and mugs);
- From 5.0 to 0.5 ppm, for cups and mugs;
- From 2.5 to 1.0 ppm for large (greater than 1.1 liters) hollowware such as bowls (but not pitchers).¹⁸⁰

These guideline levels for ceramics are expected to reduce lead emissions from ceramic manufacturers. However, the leaded glaze content of certain non-food ceramic products (such as tiles) is not expected to be affected. A list of ceramicware manufacturers in the United States is presented in Table 6-10; a list of ceramic tile manufacturers in the United States is presented in Table 6-11.

In addition to lead in ceramic glazes, metal cookware is often enameled because of the heat resistance, ease of cleaning, permanent color, and corrosion resistance of enamel. Typical enamel compositions for aluminum cookware contain 35 to 42 percent lead monoxide.¹⁴ A list of manufacturers of enamels for stove and range use is presented in Table 6-12.

A breakout of U.S. consumption of lead specific to ceramic products is not available. However, total consumption of lead oxides in glass and ceramic products and paint was estimated at 59 tons (53 Mg) in 1992.⁵⁰

TABLE 6-10. MANUFACTURERS OF CERAMICWARE

Facility	Location
Bennington Potters, Inc	Bennington, VT
Buffalo China, Inc. ^a	Buffalo, NY
Burden China Co., Inc.	El Monte, CA
Ebaz Systems, Inc.	Williamsburg, VA
Frankoma Pottery ^a	Sapulpa, OK
Haeger Potteries, Inc. ^a	Dundee, IL
Homer Laughlin China Co.	Newell, WV
Innovative Ceramic Corporation	East Liverpool, OH
Kingwood Ceramic, Inc.	East Palestine, OH
Lenox Inc. ^b	Pomona, NJ Kinston, NC
Mayer China Co.	Beaver Falls, PA
Nelson McCoy Ceramic Co.	Roseville, OH
Pewabic Pottery	Detroit, MI
Sterling China Co. ^c	Wellsville, OH
Syracuse China Corporation	Syracuse, NY

Source: Reference 181

^a Listed in the 1992 TRI under SIC code 3269 (Pottery Products, NEC). Source Reference 159

^b Listed in the 1992 TRI under SIC code 3262 (Vitreous China Table & Kitchenware). Source Reference 159.

^c Listed in the 1992 TRI without an SIC code. Source Reference 159.

TABLE 6-11. DECORATIVE CERAMIC TILE MANUFACTURERS

Facility	Location
Acme Brick Co.	Fort Worth, TX
American Olean Tile Co., Inc. ^a /Dal-Tile Corporation ^b	Lansdale, PA
Dal-Tile Corporation	Dallas Texas
Florida Tile ^b	Lakeland, FL
Monarch Tile ^b	Florence, AL
American Marazzi ^b	Sunnyvale, TX
Bennington Pottery, Inc.	Bennington, VT
Lone Star Ceramics Co.	Dallas, TX
Mannington Ceramic Tile, Inc.	Lexington, NC
Metropolitan Ceramics, Inc.	Canton, OH
Pewabic Pottery	Detroit, MI
Stark Ceramics, Inc. ^c	East Canton, OH
Winburn Tile Manufacturing Co.	Little Rock, AR

Source: Reference 181.

^a Listed in the 1992 TRI under SIC code 3253 (Ceramic Wall and Floor Tile) with reported lead compound emissions of 2 lb/yr. Source Reference 159.

^b Source: Reference 184

^c Listed in the 1992 TRI under SIC code 3251 (Brick and Structural Clay Tile). Source Reference 159.

TABLE 6-12. MANUFACTURERS OF ENAMELS FOR STOVE AND RANGE USE

Facility	Location
A.O. Smith, Protective Coatings Division	Florence, KY
Randolph Products Co.	Carlstadt, NJ
Schenectady Chemicals	Schenectady, NY
Ferro Corporation, Frit Division	Cleveland, OH
Chit-Vit Corporation	Urbana, OH
Sterling Group	Sewickley, PA

Source: Reference 183

6.6.1 Process Description

Prior to glaze application, the frit and other glaze materials are ground in a ball mill until they reach a particular size distribution that will permit uniform application, but not so fine that the lead exceeds solubility standards.¹⁴

Leaded glaze is applied to ceramics either by spraying or dipping.¹⁷⁸ Spraying is probably the most common method of glaze application in the ceramic industry. Various types of automatic glaze sprayers have been developed. These sprayers may be circular or a straight conveyor line. They are generally capable of rotating the ware and have multiple spray guns, which can be oriented according to the item being sprayed, allowing even application of glaze thickness.¹⁴

Dipping is an older process for glaze application, and is generally used only on shapes that are not conducive to spraying. Flat surfaces (such as wall tile) can be glazed using a waterfall technique--passing the tiles under a thin falling sheet of glaze.¹⁴

6.6.2 Emissions

When leaded glazes are used, lead is emitted during the glaze spraying phase. One uncontrolled emission factor for lead measured from a spray booth stack during ceramic glaze spraying is presented in Table 6-13. The glaze being used during this test contained 28.3 weight percent lead monosilicate. The test was conducted using combined EPA Methods 5 and 12 sampling trains.¹⁸⁴ Although no lead emission factors were identified for other steps in the ceramic process, lead emissions can also occur during the firing of glazes.¹⁸⁵ Two emission control options frequently used at ceramic kilns are (1) the limestone gravel-bed filter, and (2) dry scrubbing.¹⁸⁵

Because of the special properties that lead imparts to ceramic glazes, it will continue to be used in the ceramic industry. However, work is continuing in the United States to identify ways to lower the lead solubilities of commercial ceramic frits.¹⁴

6.6.3 Piezoelectric Ceramics

Lead-based ceramics are reported to be “critically important” to the electronics industry. These are piezoelectric materials, which are used to convert mechanical to electrical energy. Currently, the most widely used piezoelectric ceramic is lead zirconate titanate (PZT). Some of the applications for piezoelectric ceramics include igniters for gas appliances, cigarette lighters, remote control of appliances, tone generators, and electronic displays. These ceramics contain 60 to 64 percent lead (65 to 69 percent lead oxide).¹⁴ Multilayer ceramic capacitors are becoming more widely used in electronic circuits, especially with the trend toward miniaturization and surface-mount technology.¹⁸⁶ A list of PZT manufacturers as well as manufacturers using PZT in electronic applications is presented in Table 6-14.

TABLE 6-13. LEAD EMISSION FACTOR FOR CERAMIC/GLAZE APPLICATION

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg) ^a	Emission Factor Rating
3-09-060-01	Ceramic Glaze Spraying - Spray Booth	None	3.0 (1.5)	B

Source: Reference 184

^a Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of ceramic glaze applied.

TABLE 6-14. MANUFACTURERS OF LEAD ZIRCONATE TITANATE (PZT) AND
MANUFACTURERS OF PIEZOELECTRONICS

Facility	Location
American Piezo Ceramics, Inc.	Mackeyville, PA
Bullen Ultrasonics, Inc.	Eaton, OH
Cerac Inc.	Milwaukee, WI
Channel Products, Inc.	Chesterland, OH
Channel Technologies, Inc.	Santa Barbara, CA
Edo Corp., Electro Ceramic Division ^a	Salt Lake City, UT
Enprotech Corporation	Pittsburgh, PA
Hoechst CeramTec North America, Inc.	Mansfield, MA
International Transducer, Inc.	Santa Barbara, CA
Materials Research & Analysis (MRA) Laboratories, Inc.	North Adams, MA
Motorola, Inc. Ceramics Products ^a	Albuquerque, NM
NTK Technical Ceramics	Springfield, NJ
	Mesa, AZ
Piezo Kinetics, Inc.	Bellefonte, PA
Radio Materials Corporation	Attica, IN
Tam Ceramics, Inc.	Niagara Falls, NY
Ultran Labs, Inc.	State College, PA
Ultrasonic Powders, Inc.	South Plainfield, NJ
Vernitron Corp., Piezoelectric Division	Cleveland, OH

Source: Reference 181

^a Listed in the 1992 TRI under SIC code 3679 (Electronic Components, NEC). Source: Reference 159.

Process Description

The process for manufacturing a multilayer ceramic capacitor (MLCC) is shown in Figure 6-6. The process begins with casting a ceramic film on a removable substrate, such as a plastic film. When the film is dry, it is punched into squares, and multiple internal electrode patterns are screened onto it. These films are then stacked and laminated by applying heat and pressure to form a green MLCC bar. This bar is cut into individual MLCC chips and then fired. End termination electrodes are applied by dip-coating both ends of the chip and firing at 1472°F (800°C) to connect the internal electrodes.¹⁸⁶

Emissions

Lead emissions are expected to occur during PZT manufacture, handling of raw materials, casting, and ceramic firing. Because these PZT ceramics require no glazing, lead emissions are expected to be much lower than those from manufacture of ceramics and decorative tiles. No lead emission factors were identified for PZT ceramic manufacturers.

6.7 MISCELLANEOUS LEAD PRODUCTS

The following categories (in decreasing order of lead usage) are the most significant sources of lead emissions in the miscellaneous lead products group: ammunition, type metal, and other metallic lead products (including bearing metals, and pipe and sheet lead). Since 1992, U.S. can manufacturers no longer use lead solder. Also, the EPA has recently proposed a regulation under the Toxic Substances Control Act to prohibit the manufacture of lead-containing fishing sinkers.¹⁸⁷ Therefore, neither can solder nor fishing sinkers are included as miscellaneous lead products in this section. Also, information on abrasive grain processing is included in this section. Available information indicates that this process is likely to emit metals (including lead) as constituents of the feed material.

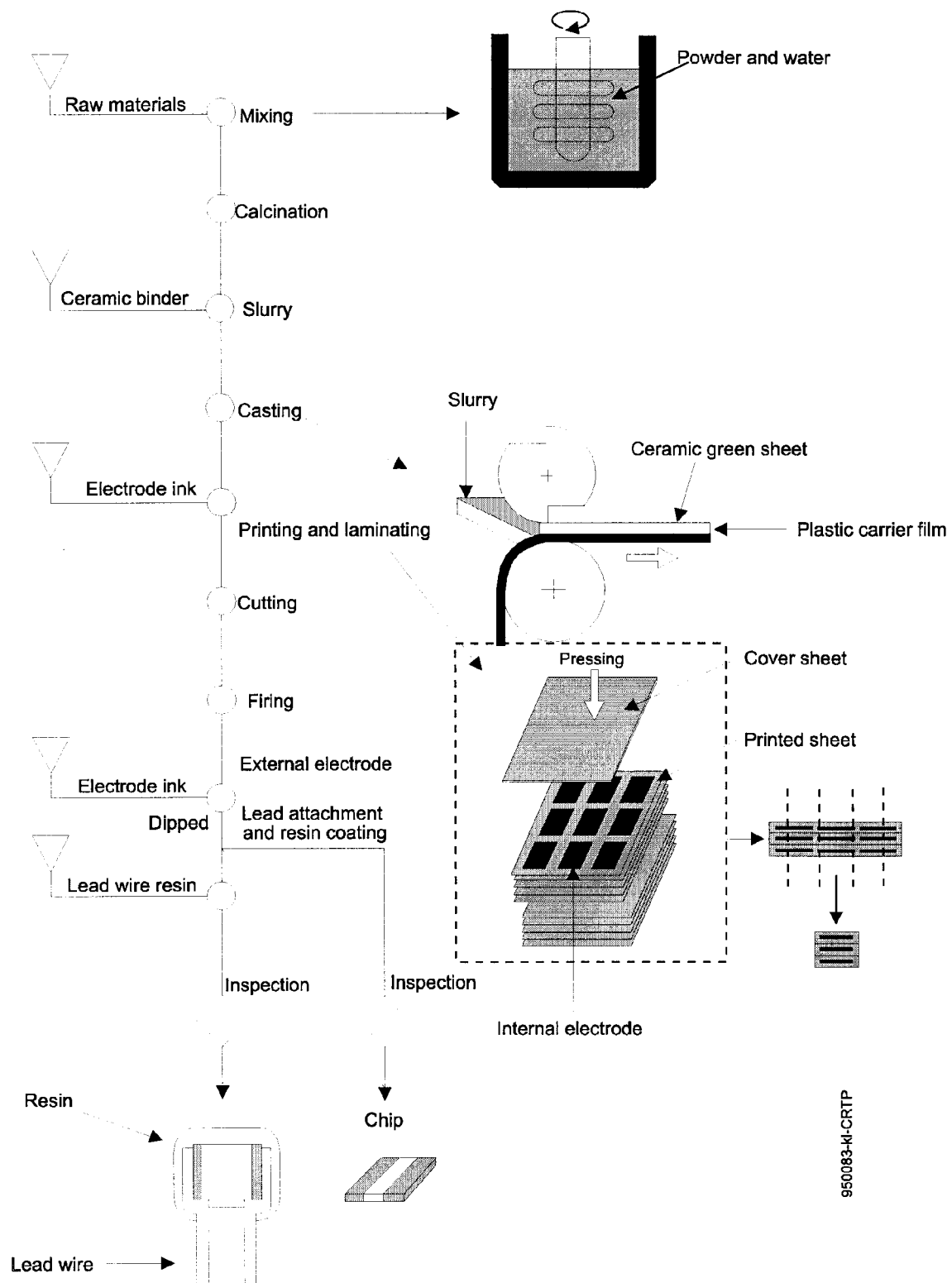


Figure 6-6. Multilayer Ceramic Capacitor Manufacturing Process

6.7.1 Ammunition

Lead is consumed and emitted in the manufacture of ammunition. Approximately 58,000 tons of lead were consumed for ammunition production in 1996.¹⁷⁵ Lead used in the manufacture of ammunition is processed by melting and alloying before it is cast, sheared, extruded, swaged, or mechanically worked in the production of lead shot or lead-filled ammunition. Some lead is also reacted to form lead azide or lead styphnate, a detonating agent.

Emissions

A lead emission factor for ammunition production is presented in Table 6-15. The emission factor represents a manufacturing scenario where little or no air pollution control equipment was used. Lead emissions from ammunition manufacturing are controlled by fabric filters, wet scrubbers and/or cyclone separators, depending on the manufacturing situation.¹⁸⁸

A total of 206 facilities manufacturing small arms ammunition (Standard Industrial Classification - 3482) nationwide were identified as being potential sources of lead emissions.¹⁸⁹

There is not enough evidence to indicate that large weapons manufacturing facilities (Standard Industrial Classification - 3483) emit significant amounts of lead.¹⁸⁹

6.7.2 Type Metal Production

Lead type has been used primarily in the letterpress segment of the printing industry. However, in the late 1980s, the printing industry started phasing out the use of lead type. The use of lead type has decreased in the last few years, but still continues to be used at some facilities. Lead typemaking processes are classified according to the methods of producing the final product: linotype, monotype, and stereotype. Because type metal is recycled many times before it is spent, the quantity of type metal actually processed in a particular year can not be calculated.

TABLE 6-15. LEAD EMISSION FACTORS FOR MISCELLANEOUS LEAD PRODUCTS

SCC Number	Process/Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg)	Emission Factor Range in lb/ton (kg/Mg)	Emission Factor Rating	Reference
3-04-051-01	Ammunition	None	<1.0 ($<5.0 \times 10^{-1}$)	---	C	57,174
3-04-051-02	Bearing Metals	None	Negligible	---	C	57,174
3-04-051-03	Other Metallic Lead Processes	None	1.5 (7.5×10^{-1})	---	C	57,174
3-05-035-05	Abrasive Grain Processing/Washing/Drying	Wet Scrubber	4.4×10^{-3} (2.2×10^{-3})	---	E	190

"---" means data are not available.
Based on 1973 data.

Process Description

Linotype and monotype processes produce a mold; the stereotype process produces a plate. All three processes are closed-cycle. The type is cast from a molten lead alloy and then remelted after printing. A small amount of virgin metal is added periodically to the melting pot to adjust the alloy and meet make-up requirements.

All type metal is an alloy consisting mainly of lead and much smaller amounts of antimony and tin. Each constituent provides a desired metallurgical characteristic for a slug (a solid bar with raised letters in a line) or other form of type-casting. Lead constitutes 60 to 85 percent of the type metal because it has a low melting point. Antimony lends hardness to the alloy and minimizes contraction as the metal cools. The antimony expands as the slug solidifies, providing a clear type face. Tin gives both strength and fluidity to the type metal and provides a smooth and even surface to the slug.

Emissions¹⁷⁴

The melting pot is the major source of emissions in type metal production. Melting the dirty recycled type metal, contaminated with printing ink, paper, and other impurities, generates smoke that contains hydrocarbons as well as lead particulates. Only small quantities of particulates are created by the oxidation of lead after the meltdown because of the protection afforded by the layer of dross on the metal surface. Limited test data indicate that lead may comprise as much as 35 percent of the total amount of PM emitted.^{191,192} Table 6-16 presents lead emission factors for type metal production.

The transferring and pouring of the molten metal into the molds may produce fuming because of surface oxidation of the metal. The trimming and finishing operations emit lead particles. However, the particles are typically large in size and tend to settle out in the vicinity of the trimming saws and finishing equipment.

TABLE 6-16. LEAD EMISSION FACTOR FOR TYPE METAL PRODUCTION

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg) ^a	Emission Factor Range in lb/ton (kg/Mg) ^a	Emission Factor Rating
3-06-001-01	Type Metal Production/ Remelting	^b	2.5x10 ⁻¹ (1.3x10 ⁻¹)	---	C

Source: References 31,173,194

^a Emission factor is expressed in lb (kg) of pollutant emitted per ton (Mg) of lead processed.

^b The emission factor is an industry average. Typical control devices utilized by the industry are cyclones, wet scrubbers, fabric filters, and electrostatic precipitators, which may be used in various combinations.

"---" means data are not available.

The most frequently controlled sources at hot metal printing facilities are the main melting pots and drossing areas. Linotype melting pots and finishing equipment do not require emission controls when they are operated properly. Emission control devices in current use include wet scrubbers, baghouses, and electrostatic precipitators. These can be used in various combinations. During drossing, the enclosure doors are opened and pot emissions may enter the plant atmosphere unless vented to a control device or to the outside.

6.7.3 Other Metallic Lead Products

Lead is also consumed and emitted in the manufacture of other metallic lead products such as bearing metals, caulking lead, pipe and sheet lead, casting metals, solder, andterne metal. Lead is also used for galvanizing, annealing, and plating. Approximately 68,100 tons of lead were consumed in the manufacturing operations of these metallic lead products in 1991.¹⁹³

Process Description

Lead is used in the manufacture of bearing metals by alloying it with copper, bronze, antimony, and tin to form various alloys. Bearings are used in electric motors, machines,

and engines. In the manufacturing of other metallic lead products, lead is usually processed by melting and casting, followed by mechanical forming operations.

Emissions

Table 6-15 presents a lead emission factor for manufacturing processes of miscellaneous metallic lead products. Uncontrolled emissions from bearing metals operations are considered negligible. There is little or no published information on control techniques or practices used for these sources.

6.7.4 Abrasive Grain Processing

Abrasive grain manufacturers produce materials for use by bonded and coated abrasive product manufacturers during production of abrasive products.

Process Description¹⁹⁰

The most commonly used abrasive materials for abrasive grain manufacturing are silicon carbide and aluminum oxides. These synthetic materials account for as much as 80 to 90 percent of the abrasive grains produced domestically. Other materials used for abrasive grains are cubic boron nitride (CBN), synthetic diamonds, and several naturally occurring minerals such as garnet and emery. The use of garnet as an abrasive grain is decreasing. CBN is used for machining the hardest steels to precise forms and finishes. The largest application of synthetic diamonds has been in wheels for grinding carbides and ceramics. Natural diamonds are used primarily in diamond-tipped drill bits and saw blades for cutting or shaping rock, concrete, grinding wheels, glass, quartz, gems, and high-speed tool steels. Other naturally occurring abrasive materials (including garnet, emery, silica sand, and quartz) are used in finishing wood, leather, rubber, plastics, glass, and softer metals.

Silicon carbide is manufactured in a resistance arc furnace charged with a mixture of approximately 60 percent silica sand and 40 percent finely ground petroleum coke. A small

amount of sawdust is added to the mix to increase its porosity so that the CO formed during the process can escape freely. Common salt is added to the mix to promote the carbon-silicon reaction and remove impurities in the sand and coke. During the heating period, the furnace core reaches approximately 4,000°F (2,200°C), at which point a large portion of the load crystallizes. At the end of the run, the furnace contains a core of loosely knit silicon carbide crystals surrounded by unreacted or partially reacted raw materials. The silicon carbide crystals are removed to begin processing into abrasive grains.

Fused aluminum oxide is produced in pot-type electric arc furnaces with capacities of several tons. Before processing, bauxite, the crude raw material, is calcined at about 1,740°F (950°C) to remove both free and combined water. The bauxite is then mixed with ground coke (about 3 percent) and iron borings (about 2 percent). An electric current is applied and the intense heat, on the order of 3,700°F (2,000°C), melts the bauxite and reduces the impurities that settle to the bottom of the furnace. As the fusion process continues, more bauxite mixture is added until the furnace is full. The furnace is then emptied and the outer impure layer is stripped off. The core of aluminum oxide is then removed to be processed into abrasive grains.

CBN is synthesized in crystal form from hexagonal boron nitride, which is composed of atoms of boron and nitrogen. The hexagonal boron nitride is combined with a catalyst such as metallic lithium at temperatures in the range of 3,000°F (1,650°C) and pressures of up to 1,000,000 pounds per square inch (psi) (6,895,000 kilopascals [kPa]).

Synthetic diamond is manufactured by subjecting graphite in the presence of a metal catalyst to pressures in the range of 808,000 to 1,900,000 psi (5,571,000 to 13,100,000 kPa) at temperatures in the range of 2,500 to 4,500°F (1,400 to 2,500°C).

Figure 6-7 presents a process flow diagram for abrasive grain processing. Abrasive grains for both bonded and coated abrasive products are made by graded crushing and close sizing of either natural or synthetic abrasives. Raw abrasive materials first are crushed by primary crushers and then reduced by jaw crushers to manageable size, approximately

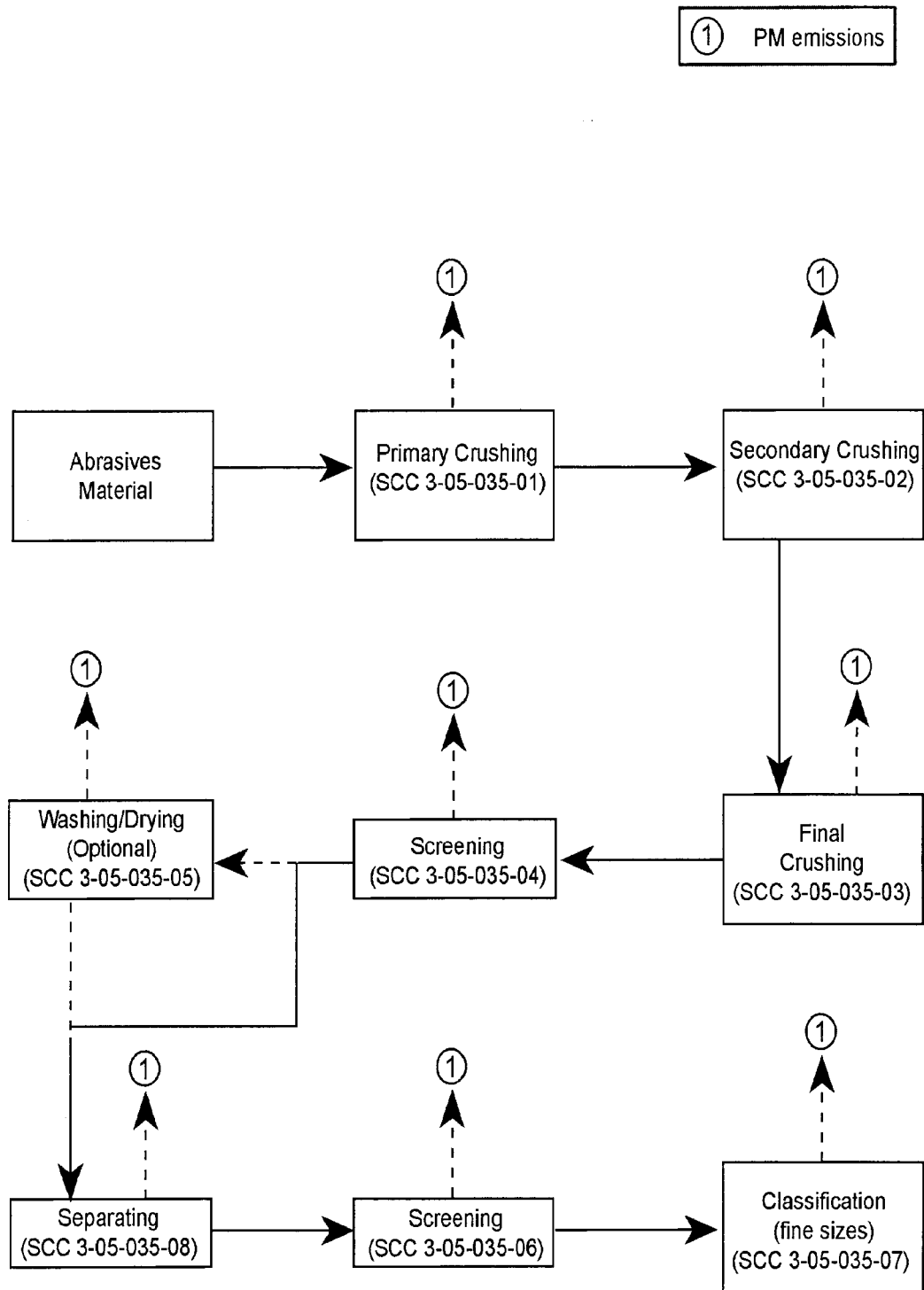


Figure 6-7. Flow Diagram for Abrasive Grain Processes

Source: Reference 190.

0.75 inches (in) (19 millimeters [mm]). Final crushing is usually accomplished with roll crushers that break up the small pieces into a usable range of sizes. The crushed abrasive grains are then separated into specific grade sizes by passing them over a series of screens. If necessary, the grains are washed in classifiers to remove slimes, dried, and passed through magnetic separators to remove iron-bearing material before they are again closely sized on screens. This careful sizing is necessary to prevent contamination of grades by coarser grains. Sizes finer than 250 grit (0.10 mm) are separated by hydraulic flotation and sedimentation or by air classification.

Emissions ¹⁹⁰

Little information is available on emissions from the manufacture of abrasive grains and products.

Emissions from the production of synthetic abrasive grains, such as aluminum oxide and silicon carbide, are likely to consist primarily of PM, PM₁₀, and CO from the furnaces. Aluminum oxide processing takes place in an electric arc furnace and involves temperatures up to 4,710°F (2,600°C) with raw materials of bauxite ore, silica, coke, iron borings, and a variety of minerals that include chromium oxide, cryolite, pyrite, and silane. This processing is likely to emit fluorides, sulfides, and metal constituents of the feed material.

The primary emissions from abrasive grain processing consist of PM and PM₁₀ from the crushing, screening, classifying, and drying operations. PM is also emitted from materials handling and transfer operations. Table 6-15 presents a lead emission factor developed from the results of a metals analysis conducted on a rotary dryer controlled by a wet scrubber in an abrasive grain processing facility.

Fabric filters preceded by cyclones are used at some facilities to control PM emissions from abrasive grain production. This configuration of control devices can attain controlled emission concentrations of 37 micrograms per dry standard cubic meter (0.02 grains per dry standard cubic foot) and control efficiencies in excess of 99.9 percent. Little other information is available on the types of controls used by the abrasives industry to control PM

emissions. However, it is assumed that other conventional devices such as scrubbers and electrostatic precipitators can be used to control PM emissions from abrasives grain and products manufacturing.

6.8 SOLDER MANUFACTURING

6.8.1 Source Description

A small fraction of the total lead produced is transformed into solder. Lead content in solder can range from 0 to over 50 percent. Industrial trends are showing an increased demand for lead-free solder, partially in response to the June 1988 amendments to the Safe Drinking Water Act, which set limits of 0.02 percent lead in solders and fluxes and 8 percent lead in pipe and fittings used in public water supply systems and facilities connected to them. Lead used in soldered food and soft drink cans declined steadily through the 1980s. As of November 1991, cans made with lead-containing solder were no longer manufactured in the United States.¹⁹⁵

In 1989, the solder manufacturing industry was comprised of 175 facilities involved in melting and realloying solder into ingots, extruding or stamping solder, and/or paste solder production. Lead emissions from the solder manufacturing industry are estimated as negligible.¹⁹⁶

6.8.2 Process Description

Lead and tin pigs are melted and blended in a kettle. The alloy is cast into billets in the slug molds and put into a press, where it is hydraulically extruded at 15,000 psi through holes 1/2 inch in diameter. The solder is wire-spoiled and put through a drawing machine to produce threads of varying diameters. After extrusion, wire stock can go to the rolling mills (rather than being spoiled), where it is formed into a solder ribbon from which washers are stamped.¹⁹⁷

Paste solder is produced by alloying various amounts of tin and lead or silver or lead oxide. The alloy is put into a powder form by centrifuging or spraying. The solder powder is mixed with a vehicle (water-based or other solvents plus additional ingredients).¹⁹⁷

The main processes of solder manufacturing--melting and paste solder production--are similar to the melting phase and paste production, respectively, in lead-acid battery production. Refer to Section 6.2 for the process description of lead-acid battery production.¹⁹⁶

6.8.3 Emissions

Studies conducted by EPA concluded that the solder manufacturing industry is a minimal source of lead emissions. This research identified two areas of solder manufacturing as potential sources of lead emissions, the lead melting process and solder paste production. Lead emissions from these sources occur by the same mechanism as lead emissions from lead-acid battery production, but the amount of lead released is expected to be much less because of the lower lead content of the alloy produced by solder manufacturing. Uncontrolled lead emissions from paste solder production are estimated to be small because the size and density of the particles have settling velocities sufficient to prevent migration to the atmosphere.¹⁹⁶

Lead emissions from solder manufacturing facilities are estimated to be decreasing because of a higher demand for lead-free solder. Many solder producers are substituting tin/antimony or tin/antimony/silver solders for the previously manufactured lead solders. Table 6-17 presents a controlled emission factor that was developed from emissions test data.

Lead will generally be emitted in particulate form from solder manufacturing facilities. Therefore, control devices effective for PM removal include fabric filters and scrubbers. Refer to Section 6.2.3 for a more detailed description of devices used to control emissions from lead-acid battery facilities, which are similar in process to solder manufacturing facilities.

TABLE 6-17. LEAD EMISSION FACTOR FOR SOLDER MANUFACTURING FACILITIES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg) ^a	Emission Factor Range in lb/ton (kg/Mg) ^a	Emission Factor Rating
3-04-004-14	Lead Melting Pot	Afterburner/ Scrubber	4.6x10 ⁻² (2.3x10 ⁻²)	---	D

Source: Reference 198

^a Emission factors are expressed in lb (kg) of lead emitted per ton (Mg) of materials processed.

"---" means data are not available.

6.9 ELECTROPLATING (INCLUDING PRINTED CIRCUIT BOARDS)

6.9.1 Source Description

Electroplating is used to coat base materials with lead or to act as a means of soldering printed circuit boards. With advances in the electronics industry creating complex parts, the use of electroplating has grown dramatically. Currently, electroplating can easily and efficiently complete 30,000 or more connections on a single circuit board. Table 6-18 presents those companies that are involved with lead electroplating operations.

6.9.2 Process Description

A flow diagram for a typical electroplating process for the coating of parts other than printed circuit boards is presented in Figure 6-8. Prior to plating, the parts undergo a series of pretreatment steps to smooth the surface of the part and to remove any surface soil, grease, or oil. Pretreatment steps include polishing, grinding, and/or degreasing of the part to prepare for plating. The part being plated is rinsed after each step in the process to prevent carry-over of solution that may contaminate the baths used in successive process steps.

Polishing and grinding are performed to smooth the surface of the part. Degreasing is performed either by dipping the part in organic solvents or by vapor degreasing the

TABLE 6-18. LEAD ELECTROPLATING MANUFACTURERS

Company	Location
CP Chemicals Inc.	Fort Lee, NJ
CuTech Inc.	Hatfield, PA
Enthone-OMI Inc.	New Haven, CT
GSP Metals & Chemicals Corp.	Los Angeles, CA
General Chemical Corp.	Parsippany, NJ
Harstan Div., Chemtech Industries Inc.	St. Louis, MO
JacksonLea, A Unit of Jason Inc.	Conover, NC
LeaRonal Inc.	Freeport, NY
MacDermid Inc.	Waterbury, CT
Maclea Chemical Co., Inc.	Chicago, IL
McGean-Rohco Inc.	Cleveland, OH
Pitt Metals & Chemicals Inc.	McDonald, PA
Quin-Tec Inc.	Warren, MI
Shipley Co., Inc.	Newton, MA
Taskem Inc.	Brooklyn Heights, OH
Technic Inc.	Pawtucket, RI
Transene Co., Inc.	Rowley, MA

Source: Reference 199.

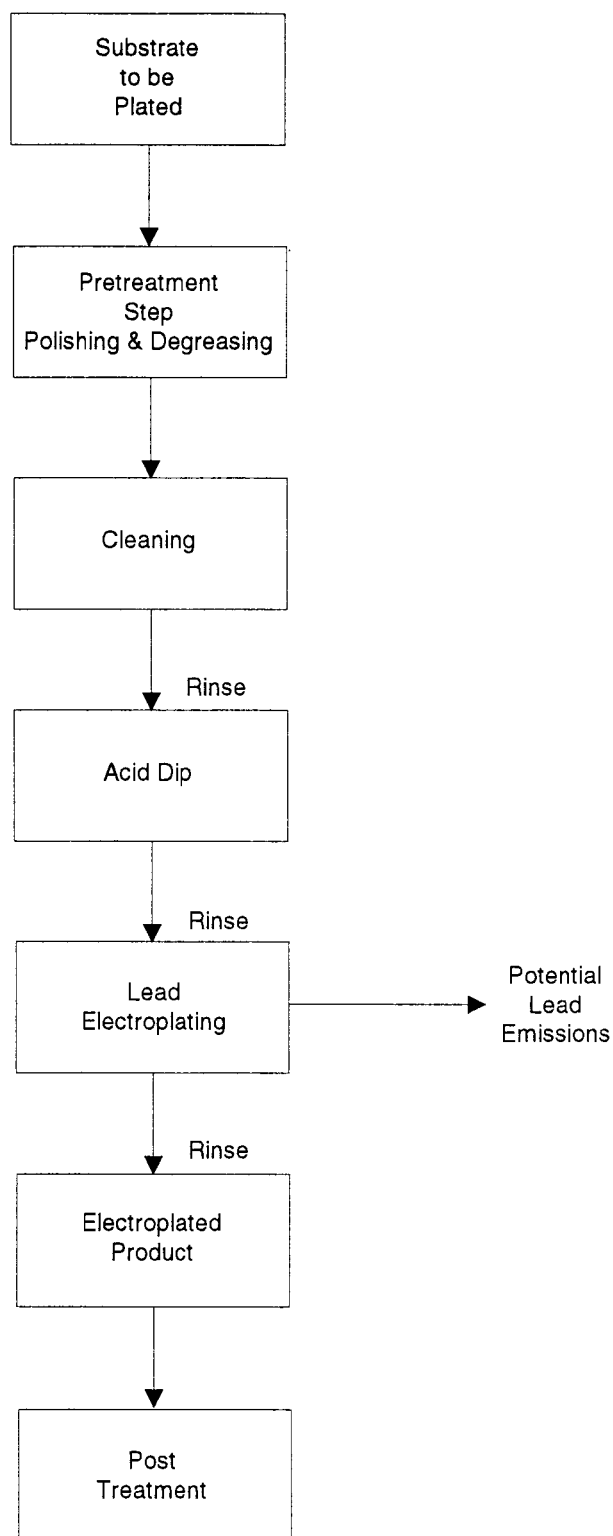


Figure 6-8. General Electroplating Process Flow Diagram

Source: Reference 200.

950200-KI-DRTP

part using organic solvents. The exact pretreatment steps used depend upon the amount of soil, grease, or oil on the parts. Following pretreatment, the parts are transferred to the plating tank.

In lead plating, the part(s) is placed in a tank and connected into the electrical circuit as the cathode. If small parts are to be plated, the parts are first placed in a plating barrel or on a plating rack. The plating barrel or plating rack is then placed in the tank and connected into the electrical circuit. As current is applied, lead ions in solution are drawn to the negatively charged cathode where they undergo reduction, resulting in the deposition of lead onto the part. The efficiency of the plating bath is based on the amount of current that is consumed in the deposition reaction versus the amount of current that is consumed by other side reactions.

Following plating, the part is thoroughly rinsed. Post-treatment of the part may be necessary.

Tin/lead solder is used in the production of circuit boards in two ways:

- Tin/lead solder is applied to the boards in the manufacturing process to protect the copper from etching during production and from oxidizing, allowing the circuit board to be stored for long periods of time.
- Tin/lead solder is used to attach components to the circuit board.

The American Electronics Association (AEA) advises that a major reason that tin/lead solder is used is because it is a conductive material that bonds aggressively. The low melting point of tin/lead solder is often preferred because of the reduced probability of thermal shock to soldered assemblies during high speed soldering operations. In addition to its ability to bond aggressively at a relatively low temperature, tin/lead solder has other advantageous physical properties, including: good wicking tendencies, i.e., the tendency to produce strong bonds by traveling up the holes to mount components to some printed circuit boards; pliancy to resist breakage from vibration; and good electrical conductivity.

Manufacturing circuit boards involves the application of tin/lead solder to maintain the circuit boards' solderability by protecting the copper boards from oxidizing. The oldest manufacturing technique employs the application of tin/lead plating to the circuit board. This process begins with a copper clad circuit board--a laminate such as fiberglass or epoxy that has been coated with copper on one or both sides. Tin/lead solder is used as a protective pattern of "etch resist," which is deposited on the copper surface, and the unwanted copper is etched away. This technique produces a copper clad circuit pattern protected by tin/lead plating.

Manufacturers of circuit boards now employ a solder-mask-over-bare copper technique that reduces the amount of solder needed in basic circuit board production. This technique is referred to as "hot air leveling." Using this technique, a solder mask, which is an organic coating such as epoxy, is applied to the bare copper board. The circuit board is then dipped into liquid tin/lead solder and forced air is used to blow excess solder back into the liquid solder (hence the term, "hot air leveling"). With this process, tin/lead solder is applied only to the joints where the components will be attached, which is about 25 percent of the exposed copper on the board, as compared to covering 100 percent of the exposed copper on the board with the tin/lead plating method.

Both tin/lead plating and hot air leveling are presently in use in the electronics manufacturing industry; however, a comparison of the frequency of use of each process is not available.

In both types of manufacturing, additional solder is applied to the circuit boards to attach the components. The soldering process is defined as a metallurgical joining method using a filler metal (the solder) with a melting point below 600°F (316°C). According to AEA, the most common soldering technique for both printed circuit board manufacturing and electronic component assembling is wave soldering. This process employs a bath of solder through which the circuit boards pass. In the assembly operations, automated equipment places electronic components on or in the printed circuit boards prior to soldering.

Surface mount assembly and through-hole assembly are two technologies used to attach electrical components to the circuit boards. With surface mount technology, components are attached directly to the circuit boards without drilling or punching holes. Without holes, the components can be densely packed on the board, thereby reducing the size of the board. Texas Instruments cites a 40 percent reduction in size of the printed circuit board assembly over through-hole technology when surface mount technology is used. With through-hole technology, the leads of the electrical components are placed in holes that have been drilled in the circuit board. Usually, the circuit board is soldered on the side from which the leads protrude.²⁰¹

For the purposes of electroplating solder on printed circuit boards, stannous fluoborate, lead fluoborate, and fluoborate acid, in various proportions, can be used for plating all percentages of tin-lead (solder), 100 percent lead and 100 percent tin. The bath requires boric acid for stability and an addition agent, usually a liquid peptone or a non-protein liquid. The addition agent provides the following advantages: (a) the solution remains clear, (b) the grain structure of the deposit is improved, (c) the throwing power of the bath is improved, and (d) better rinsing is possible and drag-out is reduced.²⁰²

6.9.3 Emissions

Lead emissions potentially occur from the plating stage of the electroplating process. However, these emissions are estimated to be low.

6.10 STABILIZERS IN RESINS

Due to its excellent insulation properties, lead is used as a component of heat stabilizers in resins. Heat stabilizers prevent the thermal degradation of resins that are exposed to elevated temperatures or ultra-violet light and weathering during end use. Lead-containing stabilizers are usually lead salts of long-chain organic acids. Typical lead stabilizers include the following compounds:²⁰³

- Diabasic lead stearate $[3\text{PbO} \cdot \text{PB}(\text{C}_{17}\text{H}_{35}\text{COO})_2]$,

- Hydrous tribasic lead sulfate ($3\text{PbO}\cdot\text{PbSO}_4\cdot\text{H}_2\text{O}$),
- Dibasic lead phthalate [$2\text{PbOPb}(\text{OCO})_2\text{C}_6\text{H}_4$], and
- Dibasic lead phosphate ($2\text{PbO}\cdot\text{PbHPO}_3\sqrt{1/2\text{H}_2\text{O}}$).

These lead-containing stabilizers are used primarily in polyvinyl chloride (PVC), vinyl chloride copolymers, and PVC blends.²⁰⁴ PVC is generally regarded as one of the most versatile of polymers because of its compatibility with many other materials, such as plasticizers, fillers, and other polymers. A list of manufacturers of heat stabilizers containing lead is presented in Table 6-19.

The major use of lead-stabilized PVC is in construction applications with a long life--for cable jacketing, conduits, and other building applications (such as siding, rainwater-resistant products, window framing, and general trim).¹⁵⁸ Lead-stabilized PVC is also used for various types of piping and fittings, including larger diameter drain and sewer pipe.^{205,206}

Other likely applications of lead-stabilized PVC include consumer products (such as appliance housings, sporting and recreational items, footwear, luggage, credit/bank cards, floppy disk jackets, window shades, blinds and awnings, industrial and garden hoses) and transportation applications (such as automobile upholstery and tops).²⁰⁵

Demand for lead stabilizers in plastics increased steadily during the 1980s due to increased demand for PVC products related to construction activity.²⁰⁶ Since that time, demand has remained relatively stable. In the 1992 Toxic Release Inventory, there were 53 facilities reporting lead and lead compound emissions from the manufacture of resins and plastics.¹⁵⁹ These facilities are listed in Table 6-20 and probably represent some of the major lead-stabilized resin and plastic manufacturers in the United States.

Products used in residential and commercial construction currently account for 70 percent of all PVC sold.²⁰⁶ Because lead is primarily used as a heat-stabilizer in these products, a list of PVC manufacturers in the United States is presented in Table 6-21.

TABLE 6-19. MANUFACTURERS OF HEAT STABILIZERS CONTAINING LEAD^a

Facility	Location
Akzo Chemical Division	New Brunswick, NJ
Hammond Lead Products, Halsted Division	Hammond, IN
Mooney Chemicals, Inc.	Cleveland, OH
M-R-S Chemicals Inc.	Maryland Heights, MO
Synthetic Products Co.	Cleveland, OH
RT Vanderbilt Co., Inc.	Norwalk, CT

Source: Reference 207.

^a Includes dibasic lead phthalate, dibasic lead phosphite, and tribasic lead sulphate.

Due to increasing pressure from state and federal agencies, U.S. manufacturers of heavy-metal heat stabilizers (including lead) are focusing research and development on finding an acceptable alternative. Some of these replacement heat stabilizers under development include magnesium-zinc, barium-zinc, and tin stabilizers.²⁰⁸

6.10.1 Process Description

Lead stabilizer production can be a highly variable process because many of the stabilizers are custom-blended for specific applications. Probably the most commonly used lead stabilizer is tribasic lead sulfate, a fine white powder that is made by boiling aqueous suspensions of lead oxide and lead sulfate. The anhydrous compound decomposes at 1,643°F (895°C). The addition of 2 to 7 percent tribasic lead sulfate to flexible and rigid PVC provides efficient, long-term, economical heat stability.²⁰⁹

Addition of the heat stabilizer additives occurs as part of the overall production of the formulated PVC resins. Formulation of the resin normally uses a blender system and, depending upon the particular PVC product, may be a batch or continuous operation.

TABLE 6-20. MANUFACTURERS OF RESINS AND PLASTICS REPORTING LEAD AND
LEAD COMPOUND EMISSIONS IN THE
1992 TOXIC CHEMICALS RELEASE INVENTORY

Facility	Location
SIC 2821: Plastics Materials and Resins	
Ampacet Corporation	Deridder, LA
BF Goodrich Company, Geovynl Division	Pedricktown, NJ
BF Goodrich Company	Louisville, KY Avon Lake, OH
North American Plastics Inc.	Madison, MS Prairie, MS
Synergistics Inc.	Howell Township, NJ
Union Carbide Chemicals and Plastics	Texas City, TX
Vista Chemical Company, Polymers Division	Aberdeen, MS
SIC 3089: Plastics Products	
American Wire & Cable Company	Olmsted Township, OH
Conex of Georgia Inc.	Greensboro, GA
KW Plastics of California	Bakersfield, CA
Lancer Dispersions Inc.	Akron, OH
RIMTEC Corporation	Burlington, NJ
WITCO Richardson Battery Parts	Philadelphia, MS
WITCO Corporation, Richardson Battery	Indianapolis, IN
SIC 3087: Custom Compound Purchased Resins	
Allied Products Corporation Coz Division	Northbridge, MA
Crown Wire & Cable Company	Taunton, MA
Gary Chemical Corporation	Leominster, MA
Heller Performance Polymers Inc.	Visalia, CA
KW Plastics	Troy, AL
Lynn Plastics Corporation	Lynn, MA

TABLE 6-20. MANUFACTURERS OF RESINS AND PLASTICS REPORTING LEAD AND LEAD COMPOUND EMISSIONS IN THE 1992 TOXIC CHEMICALS RELEASE INVENTORY (CONTINUED)

Facility	Location
Manner Plastic Materials Inc.	Rancho Dominguez, CA
Pantasote Inc., Plastic & Materials, Vinyl Compounds	Passaic, NJ
Plastics Color Chip Inc.	Asheboro, NC
PMS Consolidated	Somerset, NJ Elk Grove Village, IL Saint Peters, MO
Reed Plastics Corporation, Sandoz	Holden, MA Grand Prairie, TX
Spectra Polymer Company Inc.	Ashburnham, MA
Teknor Color Company	Henderson, KY
Teknor Apex Company	Pawtucket, RI
Vista Performance Polymers	Mansfield, MA Jeffersontown, KY
SIC 3079: Miscellaneous Plastics Products	
PVC Compounders, Inc.	Kendallville, IN
SIC 3081: Unsupported Plastic Films & Sheet	
Gencorp Polymer Products - Rigid Plastics Division	Newcomerstown, OH

Source: Reference 159.

TABLE 6-21. POLYVINYL CHLORIDE MANUFACTURERS IN THE UNITED STATES

Facility	Location	Capacity (millions of lb)
Borden Chemicals and Plastics Partnership	Geismar, LA	500
	Illioopolis, IL	350
CertainTeed Corporation	Lake Charles, LA	260
Formosa Plastics Corporation U.S.A.	Baton Rouge, LA	865
	Delaware City, DE	130
	Point Comfort, TX	1,050
The BFGoodrich Company, BFGoodrich Chemical Group	Avon Lake, OH	300
	Deer Park, TX	325
	Henry, IL	60
	Louisville, KY	400
	Pedricktown, NJ	370
Georgia Gulf Corporation	Delaware City, DE	150
	Plaquemine, NJ	840
The Goodyear Tire & Rubber Company, General Products Division	Niagara Falls, NY	115
Keysor-Century Corporation	Saugus, CA	60
Occidental Chemical Corporation, Polymers & Plastics, Vinyls Division	Baton Rouge, LA	450
	Burlington, NJ (south)	150
	Pottstown, PA	250
	Pasadena, TX	1,400
Shintech Incorporated	Freeport, TX	2,400
Union Carbide Corporation, Solvents & Coatings Materials Division	Texas City, TX	140
Vista Chemical Company, Olefins & Vinyl Division	Aberdeen, MS	440
	Oklahoma City, OK	400
Vygen Corporation	Ashatbula, OH	125
Westlake PVC Corporation	Pensacola, FL	200
Total		12,030

Source: Reference 169, 206.

The primary process used to manufacture lead-stabilized PVC in the United States is suspension polymerization. In this process, the vinyl chloride monomer is finely dispersed in water with vigorous agitation. At this point, monomer-soluble initiators and lead stabilizers in suspension are used. The particular sequence of stabilizer addition depends upon the processing method to be used (e.g., calendaring, extrusion, injection molding). The molecular weight of the PVC can be controlled by varying the temperature, where the molecular weight increases as the temperature increases.²⁰⁶

6.10.2 Emissions

No information is available for the specific types of emission control devices used to control lead emissions resulting from production of lead stabilizers or lead-containing PVC products. One potential source of lead emissions is materials handling, especially since lead stabilizers are used in powder form. Lead emissions may occur when lead stabilizers are added to the PVC resins during formulation and prior to processing the PVC resin.

Lead emissions may also be present during subsequent phases: drying, extruding, molding, grinding, weighing, packaging. However, emissions from these sources are expected to be minimal since temperatures necessary to volatilize significant quantities of lead compounds would thermally destroy the resin and other organic constituents.

No emission factors are published for this process, and no test data are available to allow calculation of an emission factor.

6.11 ASPHALT CONCRETE

6.11.1 Source Location

In 1983, there were approximately 2,150 companies operating an estimated 4,500 hot-mix asphalt plants in the United States.²¹⁰ More recently, the number has fallen to about 3,600 plants.²¹¹ Approximately 40 percent of these companies operate only a single plant.

Plants are usually located near the job site, so they are concentrated in areas with an extensive highway and road network.²¹⁰ Additional information on the location of individual hot-mix asphalt facilities can be obtained by contacting the National Asphalt Pavement Association in College Park, Maryland.

6.11.2 Process Description

To produce hot-mix asphalt (also referred to as asphalt concrete), aggregate, which is composed of gravel, sand, and mineral filler, is heated to eliminate moisture and then mixed with hot asphalt cement. The resulting hot mixture is pliable and can be compacted and smoothed. When it cools and hardens, hot-mix asphalt provides a waterproof and durable pavement for roads, driveways, parking lots, and runways.

There are three types of hot-mix asphalt plants operating in the United States: batch-mix, continuous-mix, and drum-mix. Batch-mix and continuous-mix plants separate the aggregate drying process from the mixing of aggregate with asphalt cement. Drum-mix plants combine these two processes. Production capacities for all three types of plants range from 40 to 600 tons (36 to 544 Mg) of hot mix per hour. Almost all plants in operation are of either the batch-mix or drum-mix type. Less than 0.5 percent of operating hot-mix plants are of the continuous-mix design.²¹¹

Aggregate, the basic raw material of hot-mix asphalt, consists of any hard, inert mineral material. Aggregate typically comprises between 90 and 95 percent by weight of the asphalt mixture. Because aggregate provides most of the load-bearing properties of a pavement, the performance of the pavement depends on selection of the proper aggregate.

Asphalt cement is used as the binding agent for aggregate. It prevents moisture from penetrating the aggregate and acts as a cushioning agent. Typically, asphalt cement constitutes 4 to 6 percent by weight of a hot-mix asphalt mixture.²¹⁰ Asphalt cement is obtained from the distillation of crude oil. It is classified into grades under one of three systems. The most

commonly used system classifies asphalt cement based on its viscosity at 140°F (60°C). The more viscous the asphalt cement, the higher its numerical rating.

The asphalt cement grade selected for different hot-mix asphalts depends on the type of pavement, climate, and type and amount of traffic expected. Generally, asphalt pavement bearing heavy traffic in warm climates requires a harder asphalt cement than pavement subject to either light traffic or cold climate conditions.

Another material used significantly in the production of new or virgin hot-mix asphalt is recycled asphalt pavement (RAP), which is pavement material that has been removed from existing roadways. RAP is now used by virtually all companies in their hot-mix asphalt mixtures. The Surface Transportation Assistance Act of 1982 encourages recycling by providing a 5-percent increase in Federal funds to State agencies that recycle asphalt pavement. Rarely does the RAP comprise more than 60 percent by weight of the new asphalt mixture.

Twenty-five percent RAP is typical in batch plants, and 40 to 50 percent RAP mixtures are typical in drum-mix plants.²¹⁰

The primary processes of a typical batch-mix hot-mix asphalt facility are illustrated in Figure 6-9.²¹¹ The moisture content of the stockpiled aggregate at the plant usually ranges from 3 to 5 percent. The moisture content of recycled hot-mix asphalt typically ranges from 2 to 3 percent. The different sizes of aggregate are typically transported by front-end loader to separate cold-feed bins and metered onto a feeder conveyor belt through gates at the bottom of the bins. The aggregate is screened before it is fed to the dryer to keep oversize material out of the mix.

The screened aggregate is then fed to a rotating dryer with a burner at its lower (discharge) end that is fired with fuel oil, natural gas, or propane. In the production of hot-mix asphalt, the majority of lead emissions can be expected from the rotating dryer. The dryer removes moisture from the aggregate and heats the aggregate to the proper mix temperature. Lead emissions occur primarily from fuel combustion. Aggregate temperature at the discharge end of the dryer is about 300°F (149°C). The amount of aggregate that a dryer can heat depends

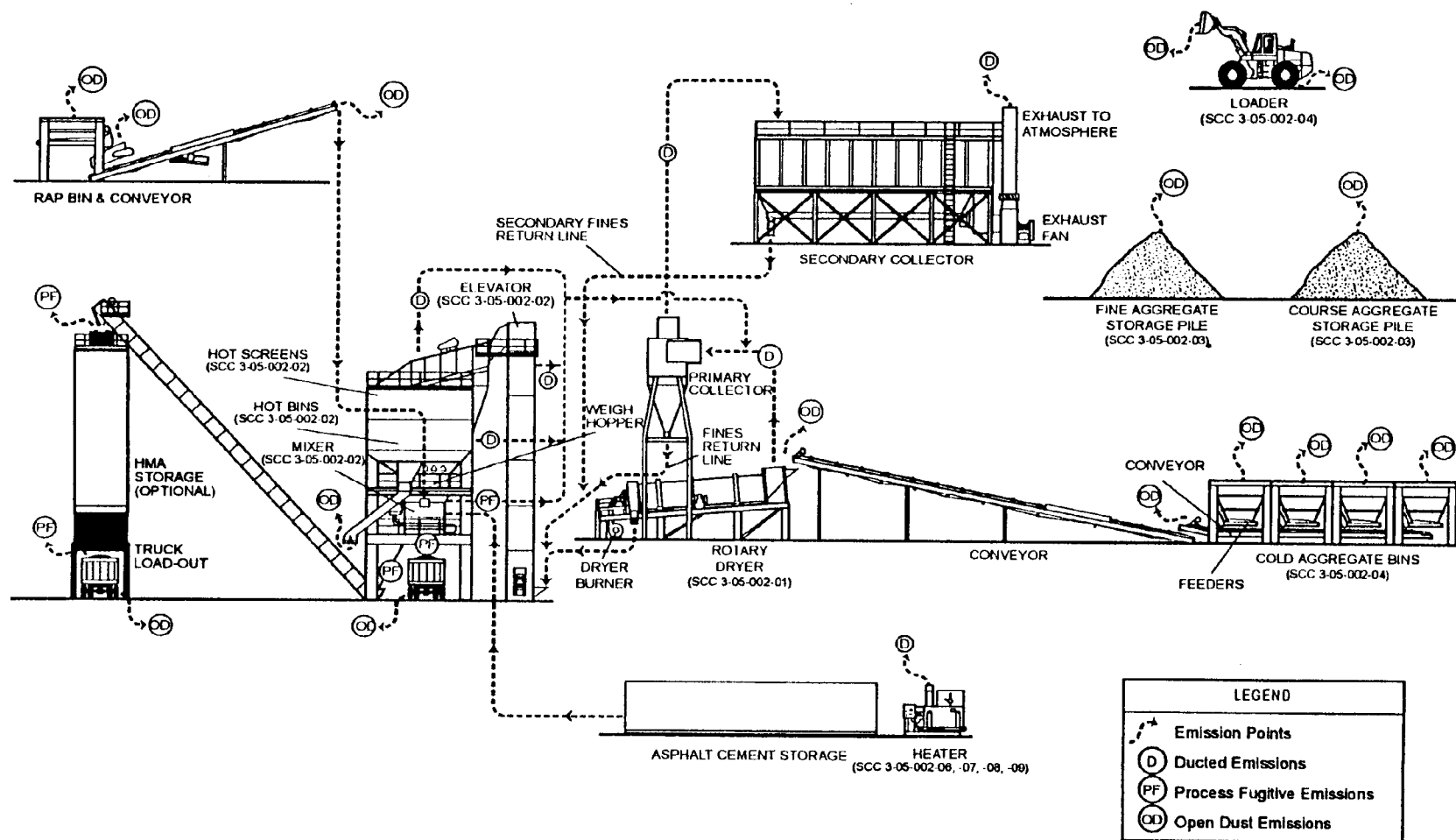


Figure 6-9. General Process Flow Diagram for Batch-Mix Asphalt Paving Plants

Source: Reference 211.

on the size of the drum, the size of the burner, and the moisture content of the aggregate. As the amount of moisture to be removed from the aggregate increases, the effective production capacity of the dryer decreases.

Vibrating screens segregate the heated aggregate into bins according to size. A weigh hopper meters the desired amount of the various sizes of aggregate into a pugmill mixer. The pugmill typically mixes the aggregate for 15 seconds before hot asphalt cement from a heated tank is sprayed into the pugmill. The pugmill thoroughly mixes the aggregate and hot asphalt cement for 25 to 60 seconds. The finished hot-mix asphalt is either loaded directly into trucks or held in insulated and/or heated storage silos. Depending on the production specifications, the temperature of the hot-mix asphalt product mix can range from 225 to 350°F (107 to 177°C) at the end of the production process.

Continuous-mix plants are very similar in configuration to batch plants. Asphalt cement is continuously added to the aggregate at the inlet of the mixer. The aggregate and asphalt cement are mixed by the action of rotating paddles while being conveyed through the mixer. An adjustable dam at the outlet end of the mixer regulates the mixing time and also provides some surge capacity. The finished mix is transported by a conveyor belt to either a storage silo or surge bin.²¹⁰

Drum-mix plants dry the aggregate and mix it with the asphalt cement in the same drum, eliminating the need for the extra conveyor belt, hot bins and screens, weigh hopper, and pugmill of batch-mix plants. The drum of a drum-mix plant is much like the dryer of a batch plant, but it typically has more flights than do batch dryers to increase veiling of the aggregate and to improve overall heat transfer. The burner in a drum-mix plant emits a much bushier flame than does the burner in a batch plant. The bushier flame is designed to provide earlier and greater exposure of the virgin aggregate to the heat of the flame. This design also protects the asphalt cement, which is injected away from the direct heat of the flame.²¹⁰

Initially, drum-mix plants were designed to be parallel-flow, as depicted in Figure 6-10. Recently, the counterflow drum-mix plant design shown in Figure 6-11 has become

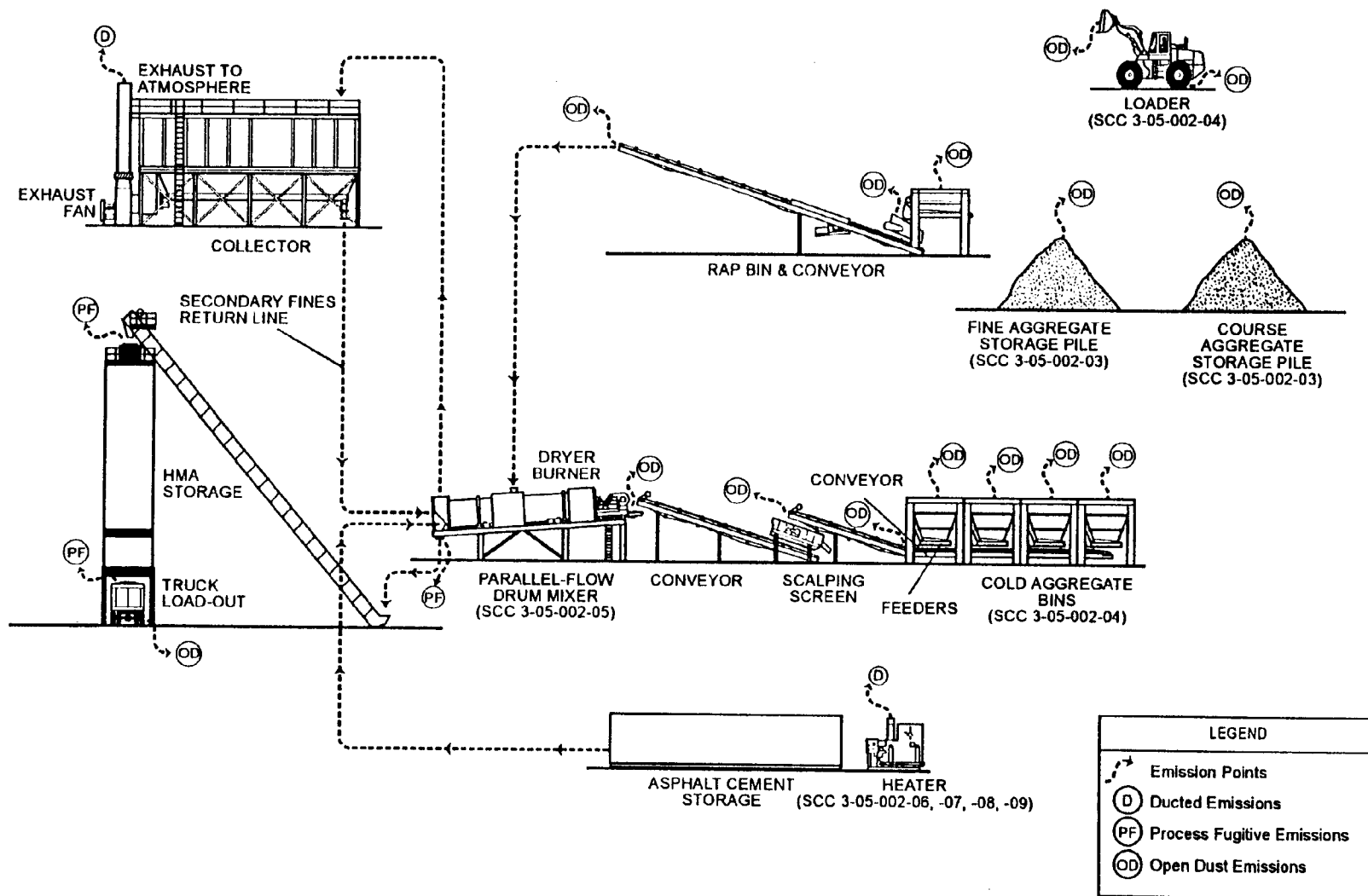


Figure 6-10. General Process Flow Diagram for Drum-Mix Asphalt Paving Plants

Source: Reference 211.

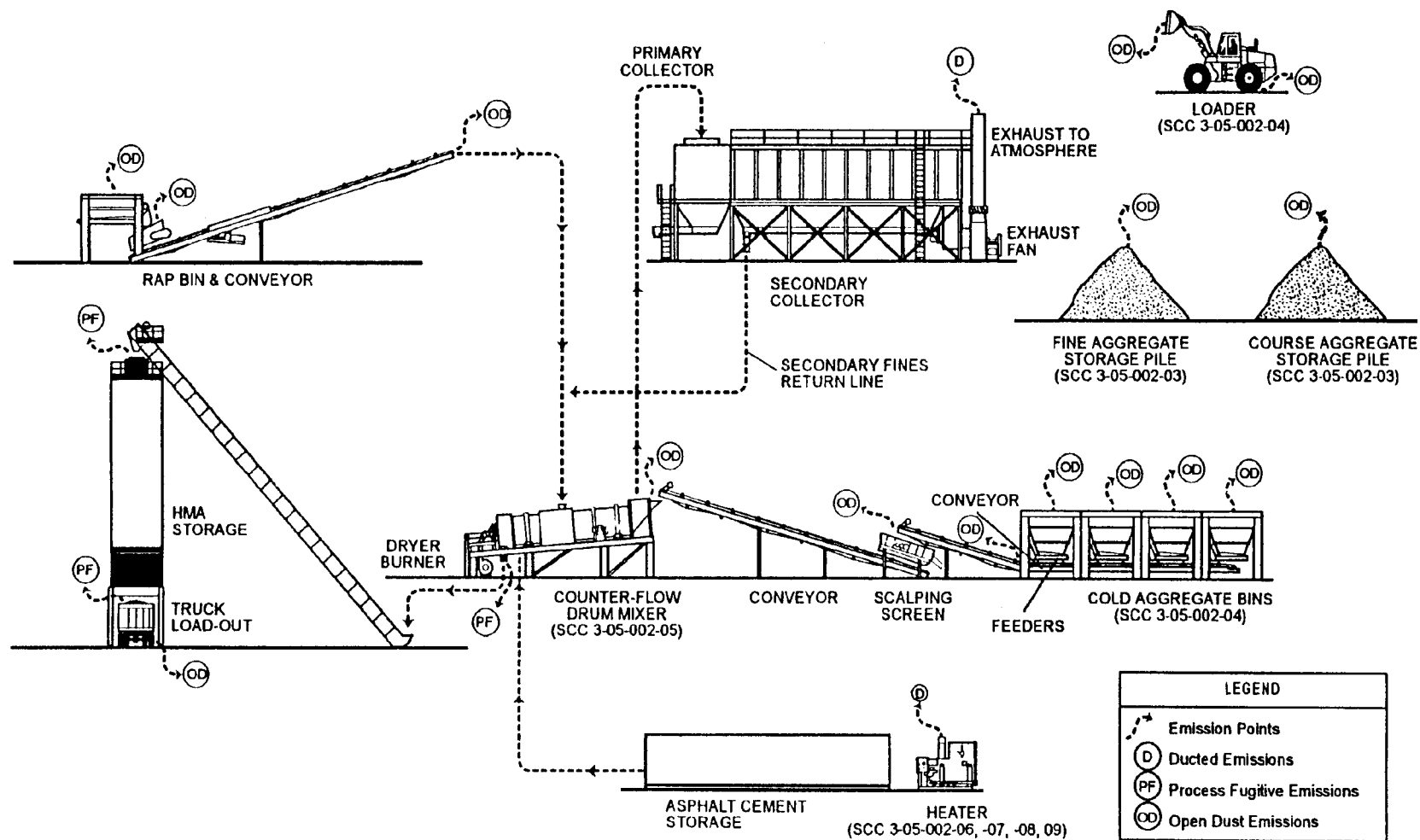


Figure 6-11. General Process Flow Diagram for Counterflow Drum-Mix Asphalt Paving Plants

Source: Reference 211.

popular.²¹¹ The parallel flow drum-mix process is a continuous-mixing type process using proportioning cold feed controls for the process materials. Aggregate, which has been proportioned by gradations, is introduced to the drum at the burner end. As the drum rotates, the aggregates and the combustion products move toward the other end of the drum in parallel. Liquid asphalt cement flow is controlled by a variable flow pump that is electronically linked to the virgin aggregate and RAP weigh scales. The asphalt cement is introduced in the mixing zone midway down the drum in a lower temperature zone along with any RAP and PM from collectors. The mixture is discharged at the end of the drum and conveyed to a surge bin or storage silos. The exhaust gases also exit the end of the drum and pass on to the collection system.²¹¹

In a counterflow drum-mix plant, the material flow in the drum is opposite or counterflow to the direction of the exhaust gases. In addition, the liquid asphalt cement mixing zone is located behind the burner flame zone so as to remove the materials from direct contact with hot exhaust gases. Liquid asphalt cement flow is still controlled by a variable flow pump and is injected into the mixing zone along with any RAP and PM from primary and secondary collectors.²¹¹

Of the 3,600 active hot-mix asphalt plants in the United States, approximately 2,300 are batch-mix plants, 1,000 are parallel-flow drum-mix plants, and 300 are counterflow drum-mix plants. About 85 percent of plants being constructed today are of the counterflow drum-mix design; batch-mix plants and parallel-flow drum-mix plants account for 10 percent and 5 percent respectively.²¹¹

Emission Control Techniques

Emissions of lead from hot-mix asphalt plants most likely occur because of fuel combustion in the aggregate rotary dryers, but some emissions from the aggregate during the drying process are possible. These emissions are most often controlled by wet scrubbers or baghouses.²¹¹

6.11.3 Emissions

Emissions from hot-mix asphalt plants were reexamined recently for the purpose of updating the information contained in the EPA's *Compilation of Air Pollutant Emission Factors*, commonly referred to as AP-42. Representative batch-mix and drum-mix plants (both parallel and counterflow) were selected for testing. Emissions from hot-oil heaters used to warm stored asphalt concrete were also evaluated. Lead emissions from hot-mix plants can result from fuel combustion, aggregate mixing and drying, and asphalt heating. The only lead emissions found from these tests were from the drying process. These lead emission factors are provided in Tables 6-22 and 6-23.²¹²

6.12 APPLICATION OF PAINTS

Leaded house paints were common up until the mid-1950s. In 1971, the Lead-Based Paint Poisoning Prevention Act prohibited the use of paints containing more than 1 percent lead by weight in the nonvolatile portion of liquid paints or in the dried film on all interior and exterior surfaces accessible to children in residential structures. In 1972, the FDA ordered a reduction of the lead content of paints used in and around households to 0.5 percent in 1973 and 0.06 percent in 1975. Further legislation in 1976 required the Department of Housing and Urban Development to prohibit lead-based paint in residential structures built or rehabilitated with federal assistance. Also, the Department of Health, Education, and Welfare banned lead paints from cooking and eating utensils, and the Consumer Products Safety Commission prohibited lead paints on toys and furniture. As a result, the use of white lead in paints for these consumer applications has plummeted in recent years.²¹³

Although the use of lead paint has dramatically decreased in these consumer products, leaded paint is still used in certain applications. The major uses of lead-based paints today are as metal primers in automobile refinishing, as anti-corrosive undercoating in the automobile industry, for public works applications (such as bridges and roads), as traffic paint, in art materials, and in marine applications (such as boats and buoys).^{213,217}

TABLE 6-22. LEAD EMISSION FACTORS FOR BATCH-MIX HOT-MIX ASPHALT PLANTS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg) ^a	Emission Factor Range in lb/ton (kg/Mg) ^a	Emission Factor Rating	Reference
3-05-002-01	Rotary Dryer	FF	7.4×10^{-7} (3.7×10^{-7})	---	D	212
		Wet Scrubber - Medium Efficiency	3.10×10^{-6} (1.55×10^{-6})	$< 2.30 \times 10^{-6}$ - 3.9×10^{-6} ($< 1.15 \times 10^{-6}$ - 1.95×10^{-6})	U	214
		Wet Scrubber - Medium Efficiency/Single Cyclone	1.03×10^{-6} (5.15×10^{-7})	6.80×10^{-7} - 1.24×10^{-6} (3.40×10^{-7} - 6.20×10^{-7})	U	215
		Single Cyclone/Baghouse	2.00×10^{-6} (1.00×10^{-6})	1.08×10^{-6} - 2.77×10^{-6} (5.40×10^{-7} - 1.39×10^{-6})	U	216
		Multiple Cyclone without Fly Ash Reinjection/Baghouse	2.08×10^{-7} (1.04×10^{-7})	3.74×10^{-7} - 4.10×10^{-6} (1.87×10^{-7} - 2.05×10^{-6})	U	92
		None	4.0 (2.0)	---	U	22

^a Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of waste incinerated.

“---” means data are not available.

FF = Fabric Filter.

TABLE 6-23. LEAD EMISSION FACTOR FOR DRUM-MIX HOT-MIX ASPHALT PLANTS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton (kg/Mg) ^a	Emission Factor Range in lb/ton (kg/Mg) ^a	Emission Factor Rating
3-05-002-05	Drum Dryer	FF	3.30x10 ⁻⁶ (1.70x10 ⁻⁶)	---	D

Source: Reference 212.

^a Emission factors are expressed in lb (kg) of pollutant emitted per ton (Mg) of hot mix asphalt produced.

“---” means data are not available.

FF = Fabric Filter.

The future trend for the paint industry is to identify substitutes for the lead compounds currently being used. However, there is no perfect substitute that can impart all of the properties of lead, which include color, brightness, cost effectiveness, insolubility, opacity, nonbleeding in solvents, and durability. At present, substitutes of acceptable quality exist for only some of these uses.²¹⁷ The major current uses of lead-based paints are discussed briefly below.

6.12.1 Source Description

Automotive Industry and Automobile Refinishing

Because lead enhances the corrosion protection and durability of surface coatings, products such as paints and primers containing lead are frequently used to coat autobody surfaces and in automobile refinishing shops.²¹⁸ White-basic lead silicochromate is used in the electrodeposition of water-based coatings for the automotive industry. Its use in this application has increased because of its capability to be tinted to a variety of colors.²¹³

Industrial Applications

Red lead is used as a rust-inhibitive pigment in paints for structural steel, such as bridges and support beams.²¹³ Basic lead silicochromate, which can be thinned with either solvent or water, is also used for its excellent anti-corrosive properties in industrial and maintenance paints.¹³ The use of lead as an anti-corrosive in steel primers is decreasing because of containment costs required for application/removal. In certain applications, titanium oxide (TiO₂) is being substituted for lead.²¹⁷

Machinery Finishes/Traffic Paints

Lead chromates are added to paints because they are inexpensive and provide durability in exterior applications. Chrome orange is used in machinery finishes, such as farm equipment and trucks. Chrome yellow is used in traffic paints--for highway stripes and markings, as well as curb markings, guard railings, and crosswalks. The pigment constitutes 25 percent of the total weight of the paint.²¹³ In 1990, about 40 million pounds of lead chromate were produced in the United States, and an additional 8 million pounds were imported.²¹⁹

Artists Paints

Oil colors contain large amounts of pigment, ranging from 30 percent for toners to as high as 80 percent with dense pigments such as white leads.²¹³

Marine Coatings

Anti-corrosive coatings are also used for marine applications, such as ship hulls, buoys, and offshore towers. Red lead has been used extensively for this purpose; however, zinc dust has largely replaced red lead. Basic lead silicochromate is also being used for corrosion protection.²¹³

6.12.2 Process Description

For some of the categories discussed above, paint is applied using a surface coating operation (such as automobiles, farm machinery, buoys, boats). For other categories, the paint is applied (either by spraying or brushing) directly on the structure or item once it has been erected (such as bridges, beams, marine towers, curbs, roads). Because the variety of applications is so diverse, detailed process descriptions are not included in this document.

Industrial surface coating operations use several different methods to apply coatings to substrates. The type of surface coating operation used will depend upon the type of product being coated, coating requirements, and the method of application. The more commonly used techniques include electrodeposition (EDP), spraying, dipping, flow coating, and brushing.

In the automobile industry, EDP is used to apply anti-corrosion lead-based paints to the underbody of vehicles. In EDP, a dc voltage is applied between the coating bath (or carbon or stainless-steel electrodes in the bath) and the part to be coated. The part (acting as either the cathode or anode) is dipped into the bath. The coating particles in the bath are attracted to the part because they have an opposite charge. The result is a very evenly applied coating. The coatings used in EDP are waterbased. Transfer efficiencies for this process are generally greater than 95 percent.²²⁰

Spraying operations are normally performed in a spray booth using one of the following spray application methods: air atomization; airless atomization; air-assisted airless; high-volume, low pressure (HVLV); and electrostatic methods. All of these techniques are used in automobile refinishing. Air atomization is also used to apply traffic markings.²²⁰

Dip coating involves briefly immersing the substrate in a tank containing a bath of paint. The object is slowly removed from the tank allowing excess paint to drain back into the tank. Flow coating is used on articles which cannot be dipped due to their buoyancy. In this operation, the coating material is fed through overhead nozzles, distributing the paint in a steady

stream over the article to be coated. Excess paint is allowed to drain from the coated object and is then recycled.²²⁰

6.12.3 Emissions

Lead emissions from paint application occur as the paint is applied--during spraying, brushing, or dipping. Lead emissions may also occur from the paint blending tank or during the drying and curing operations. Lead would be emitted as PM. Equipment used to control PM emissions from spray booth operations include baffle plates, filter pads, or water curtains.²²⁰

No specific emission factors for lead were identified for any of the paint application source categories.

6.13 SHOOTING RANGES AND EXPLOSIVE ORDNANCE DISPOSAL SITES

6.13.1 Source Description

This section presents information on two potential lead-emitting sources: shooting ranges and explosive ordnance disposal (EOD) sites. Shooting ranges include indoor firing ranges and gun clubs. Many shooting ranges nationwide were identified as being potential sources of lead emissions.^{221,222}

Various materials and explosives are regularly destroyed at ordnance disposal sites within military facilities. These facilities use open burn/open detonation (OB/OD) treatment processes to eliminate the hazardous properties of reactive waste munitions. As materials are combusted or exploded during the OB/OD treatment processes, chemical byproducts of incomplete combustion are emitted into the atmosphere.

6.13.2 Emissions

Lead is emitted from the firing of small arms ammunition with lead projectiles and/or lead primers, but the explosive charge does not contribute to lead emissions.

Indoor shooting ranges may expose firing personnel to lead during indoor shooting practices and qualification exercises. OSHA regulations may apply to indoor range situations. Ventilation systems at indoor shooting ranges should be designed with enough air flow from the firing line toward the target area to effectively remove the airborne lead generated during firing of conventional ammunition. New bullet traps are also available to reduce lead exposure generated from trap impact.

Lead emissions from small arms can be reduced by using different ammunition types and/or special leadfree primers. The Department of Defense and ammunition manufacturers are undertaking an R&D effort to develop lead free ammunition. Zinc bismuth, tungsten, nickel and plastic (among other items) are being considered as potential alternatives. None are currently available for widespread use and most are being considered for practice ammunition only. No emission factors were available for indoor shooting activities.²²³

In general, EOD processes generate relatively small quantities of pollutants. Chemical emission rates from an OB/OD event depend on the quantity and type of propellant treated and the method of treatment. Emissions originate either from the combustion or detonation of the propellant and primer material or nonenergetic waste (i.e., containers and other waste associated with the propellant) or vaporization of the nonenergetic waste (i.e., casings surrounding the propellant) during combustion. The list of propellant wastes to potentially be treated at an OB/OD facility is fairly extensive.

Table 6-24 presents lead emission factors for various categories of propellants. All emission factors are in gram emitted per gram of material burned or detonated. Each type of propellant represents a fairly different material. TNT represents a specific type of explosive. The double-based and composite-based propellants are nitroglycerin- and nitrocellulose-based

TABLE 6-24. UNCONTROLLED LEAD EMISSION FACTORS FOR EOD ACTIVITIES

Propellant Tested	Uncontrolled Average Emission Factor	Uncontrolled Emission Factor Range	Emission Factor Rating	Reference
	lb emitted/lb detonated (g emitted/g detonated)	lb emitted/lb detonated (g emitted/g detonated)		
TNT	4.1×10^{-4} (4.1×10^{-4})	---	U	221
Double-based Propellant (DB)	1.3×10^{-2} (1.3×10^{-2})	---	U	222
Composite-based Propellant (CB)	9.4×10^{-5} (9.4×10^{-5})	---	U	222
20-mm High-explosive Incendiary Cartridges	1.8×10^{-3} (1.8×10^{-3})	---	U	222
40-mm High-explosive Cartridges	1.3×10^{-3} (1.3×10^{-3})	---	U	221
M18A1 Claymore Antipersonnel Mine	5.3×10^{-7} (5.3×10^{-7})	---	U	221
T45E7 Adapter-booster	7.7×10^{-4} (7.7×10^{-4})	---	U	221
PBAN-Ammonium Perchlorate Propellant	2.2×10^{-6} (2.2×10^{-6})	---	U	224
CTPB-Ammonium Perchlorate Propellant	2.3×10^{-6} (2.3×10^{-6})	---	U	224
PEG/PBAN	1.0×10^{-6} (1.0×10^{-6})	---	U	224

Note: SCC assignment is not applicable to this category.

“---” means data are not available.

PEP; the 20-mm high-explosive incendiary and 40-mm high-explosive rounds represent RDX (2,3,5-trinitro-1,3,5-triazine) propellants with a variety of binders and additives. The M18A1 Claymore mine is primarily comprised of C4 plastic explosive with a high RDX component. The T45E7 booster represents a tetryl-based explosive. Finally, the PBAN/CTPB/PEG propellants represent ammonium perchlorate and nitrate propellants with different types of binders and stabilizers.

6.14 RUBBER PRODUCTS

Lead compounds may be added to rubber products as pigments, fillers, activators, vulcanizers, curing additives, and plasticizers. In some cases, lead metal may be included in the rubber product, such as lead-sheathed hosing.²²⁵

Lead is used as a pigment for rubber products that require color differentiation or for aesthetic appeal. Some uses of lead as a pigment in rubber products include white wall tires and markings on sporting goods such as basketballs.²²⁵ Sometimes lead chromates are used as pigments when bright yellow or orange colors are desired.²²⁶ Recent interest has developed in eliminating the use of lead-based pigments. However, lead pigments have several desirable qualities that are difficult to match, including heat and light stability, and low formulation and processing costs.²²⁶

Lead compounds used as activators and vulcanizers in rubber product include litharge (lead oxide), lead peroxide, and lead stearate. Litharge is used as a vulcanizing agent for chloroprene and polyethylacrylate natural and synthetic rubber. As an activator, litharge accelerates the curing rate and scorch time of rubber and is often combined with other accelerators.²²⁷ As an activator, litharge is used primarily in natural, styrene-butadiene, and nitrile rubbers. Red oxide and white lead are also used as activators. Table 6-25 lists some rubber products that may contain lead.²²⁵

According to the Department of Commerce, 1,650 tons (1,500 Mg) of lead were consumed by the rubber industry in 1990, with about 10 percent used for pigments. The majority of this lead was consumed in manufacturing lead sheathed hosing and for making molds for the

TABLE 6-25. END USES OF RUBBER THAT MAY CONTAIN LEAD

Tires	Tank linings
Inner tubes	High-voltage insulators
Cable coverings	Hose
Seals	Conveyor belts and belting
Automotive radiator and heating hosing	Gaskets
Footwear	Flexible bellows
Vehicle suspension and body supports	Piers and boat bumpers
Bridge bearings	Springs
Vibration insulators	Packaging
“O” rings	Rubber-coated fabric
Sealants	Mats and matting
Jar rings	Flooring
Miscellaneous sporting goods	Miscellaneous sundries

Source: Reference 225.

manufacturing process.²²⁵ Table 6-26 lists rubber product manufacturing facilities reporting lead and lead compound emissions in the 1992 Toxic Release Inventory.

6.14.1 Process Description

An emulsion process is frequently used during the manufacture of rubber (such as styrene-butadiene rubber). In this process, scrubbed monomer is dispersed in water, and additives (such as litharge, which is used as an activator) are mixed during the polymerization stage. After the polymerization reaction is complete, the polymer emulsion is blended and stored as a finished latex for subsequent processing into end products.²²⁸

TABLE 6-26. RUBBER PRODUCT MANUFACTURING FACILITIES IN THE
UNITED STATES REPORTING LEAD AND LEAD COMPOUND EMISSIONS IN 1992
UNDER SARA 313

Facility	Location
SIC 3069: Fabricated Rubber Products	
Ashtabula Rubber Company	Ashtabula, OH
Elastochem Inc.	Chardon, OH
Goodyear Tire & Rubber Company	Norfolk, NE
Kennedy Company, Inc.	Scottsboro, AL
Mach-I Compounding	Macedonia, OH
Polymeric Inc.	Cuyahoga Falls, OH
Rhein Chemie Corporation	Trenton, NJ
SIC 3052: Rubber & Plastics Hose & Belting	
Aeroquip Corporation	Mountain Home, AR Forest City, NC
Boston Industrial Products	Hohenwald, TN
Dayco Products Inc.	Ocala, FL Alliance, NE
Gates Rubber Company	Galesburg, IL Iola, KS
Rhein Chemie Corporation	Trenton, NJ
Uniroyal Goodrich Tire Company	Opelika, AL

Source: Reference 159.

6.14.2 Emissions

Although no emission factors for lead from rubber manufacturing were identified in the literature, lead emissions from this process are expected during the materials handling stage (especially since the additives are in particulate form) and while the additives are being combined with the monomers, catalysts, and other compounds during the polymerization step.

SECTION 7.0

EMISSIONS OF LEAD AND LEAD COMPOUNDS FROM MOBILE SOURCES

7.1 GENERAL

Elemental lead and lead alloys are used in the manufacture and operation of vehicles. For example, lead is used in connecting electrical components, and antimonial lead is used in bearings. The positive plate grids in automobile batteries are made of an alloy of lead, antimony, tin, arsenic, and copper. Lead is also an anticorrosive additive in automobile paint primers. Combining lead and tin produces an alloy referred to as turn or turnplate, which is used to make corrosion-resistant gas tanks.²²⁹ Lead is also an additive in automotive plastics and is included in ceramic electrical components. Despite this widespread use of lead in vehicles, the largest source of lead emissions from vehicles is from fuel combustion.

Lead has been used in motor gasoline since the 1920s to boost octane and provide lubrication for intake and exhaust valves. The lead compounds function by decomposing in the combustion cycle to form metal oxide particles. The particles interrupt the hydrocarbon chain branching reactions that cause rapid combustion, known as “knock.” Lead anti-knock compounds foiled 1970 catalytic converter technologies developed to reduce hydrocarbon, carbon monoxide, and nitrogen oxide emissions. This led to the development of lead-free fuel in the early 1970s.²³⁰

The 1970 Clean Air legislation permitted the regulation of fuel additives, established a schedule for reducing lead additives, and required automobile manufacturers to design and construct vehicles that could run on low-lead and unleaded fuel. The phase-down of leaded gasoline in highway motor vehicles began in 1973. Section 211(n) of the CAA prohibits

the manufacture of highway engines requiring leaded gasoline after 1992. In January 1992, remaining lead additives used in fuels were banned for use in on-road vehicles in California. The final deadline for the abolition of all lead-containing highway vehicle fuels was December 31, 1995.

The lead levels in leaded gasoline have been gradually reduced from the industrial average of 2.5 g lead/gal (0.66 g/L) leaded gasoline in the 1970s to 0.0002 g lead/gal (5.283×10^{-5} g/L) unleaded gasoline in 1991 (see Table 7-1). Since 1982, the majority of gasoline fuel sold for motor vehicles is lead-free. Currently, less than 1 percent of gasoline motor vehicle fuel is leaded (see Table 7-2). As of 1995, only one gasoline refinery continues to produce gasoline with lead additives.²³¹ The fuel that currently has the greatest lead content is aviation gasoline (2 to 4 g lead/gal [0.528 to 1.057 g/L]). The petroleum industry may continue to make and market gasoline produced with lead additives for non motor vehicle uses, including use as fuel in aircraft, racing cars, and non-road engines such as farm equipment engines and marine engines.²³¹ Diesel fuel is assumed to contain quantities of lead that are insignificant compared to gasoline fuel.^{17,158}

7.1.1 Leaded Fuels

The two most common lead anti-knock additives are tetraethyl lead (TEL) and tetramethyl lead (TML). TEL and TML, both high in octane, lubricate intake and exhaust valves and help reduce engine knock.²³⁰ In 1990, 93 percent of highway fuel lead additives were TEL, and the remaining 7 percent were TML. The composition and properties of TEL and TML are shown in Table 7-3.

The manufacture of TEL and TML compounds for use in gasoline was discontinued in the United States in May 1991.²³² The plants that manufactured alkylated lead compounds have been dismantled.^{232,233,234} However, TEL is still manufactured in Canada and Europe and imported by a few companies in the United States to produce leaded gasoline.^{232,235,236}

TABLE 7-1. LEAD CONTENT OF MOTOR VEHICLE FUELS

Year	Lead Content (g/gal)	
	Leaded	Unleaded
1974	2.07	0.014
1975	1.82	0.014
1976	2.02	0.014
1977	2.03	0.014
1978	1.76	0.010
1979	1.76	0.016
1980	1.33	0.0286
1981	1.01	0.009
1982	1.02	0.005
1983	0.83	0.003
1984	0.84	0.006
1985	0.59	0.002
1986	0.31	0.002
1987	0.15	0.001
1988	0.15	0.001
1989	0.002	0.002
1990	0.0004	0.0004
1991	0.0002	0.0003

Source: Reference 237.

TABLE 7-2. FUEL SALES

Year	Finished Motor Fuel (thousand barrels)		Aviation Gasoline
	Leaded	Unleaded	
1981	1,213,144	1,190,347	11,147
1982	1,142,590	1,243,032	9,306
1983	1,085,813	1,331,271	9,444
1984	990,051	1,459,410	8,692
1985	885,144	1,608,217	9,969
1986	795,697	1,771,738	11,673
1987	833,668	1,896,420	9,041
1988	490,805	2,194,340	9,705
1989	299,770	2,374,899	9,427
1990	140,571	2,500,170	8,910
1991	92,041	2,531,403	8,265
1992	38,502	2,621,411	8,133

Source: Reference 238.

The blend of TEL and TML used in motor vehicle fuel depends upon the grade of gasoline being produced. For regular gasolines (i.e., below about 93 RON [research octane number for all distillate fractions of the gasoline]), TEL is usually the preferred anti-knock additive. For premium gasolines where elevating RON is important, TEL is normally preferred for lead concentrations below 1.514 g lead/gal (0.40 g/L). Above this level, mixtures of TEL and TML may be more beneficial. For premium gasolines where MON (motor octane number--a guide to the anti-knock performance of a fuel under relatively severe driving conditions) is important, mixtures of TEL and TML are again likely to produce the best results. For premium gasolines where R100°C (research octane number of the fraction of gasoline distilled up to 100°C) is important, TML, or mixtures of TML with TEL, are likely to be most beneficial.²³⁰

Leaded fuels also contain 1,2-dibromoethane and 1,2-dichloroethane. These chemicals act as lead scavengers, preventing a buildup of lead compounds in the combustion

TABLE 7-3. COMPOSITION AND PROPERTIES OF TEL AND TML

	TEL	TML
COMPOSITION, WT %		
Lead Alkyl	61.5	50.8
1,2-dibromoethane	17.9	17.9
1,2-dichloroethane	18.8	18.8
Dye, diluent, inhibitor, etc.	1.8	12.5
Lead content, wt%	39.39	39.39
PROPERTIES		
Specific Gravity, 20°/4°C	1.6	1.58
Vapor pressure @ 20° C mbar	67	87
Boiling point of lead alkyl, °C	200 (decomposes)	110

Source: Reference 230.

chamber. These lead deposits can flake off and cause valve burning by holding valves off their seats, thus allowing the hot combustion gases to escape past the valves. During combustion, lead and halogenated additives combine to form lead halides that are exhausted from the engine.²³⁰

Of the different aviation fuels currently in use, only aviation gasoline contains lead as an anti-knock compound. Jet kerosene and JP-4 do not contain lead additives. Aviation gasoline is used in reciprocating piston-engine aircraft and is therefore more prevalent in civil aviation and general commercial aviation. There are two grades of aviation gasoline: low-lead, which has a lead concentration of 2 g lead/gal (0.528 g/L) aviation gasoline, and high-lead, which has a lead concentration of 4 g lead/gal (1.057 g/L) aviation gasoline. Only TEL is used in leaded aircraft fuel.²³⁹

Due to the economics of producing leaded gasoline, fewer refineries and blending facilities are producing it. This has caused the Federal Aviation Administration and the General Aviation Manufacturer's Association to begin a cooperative research program to develop an

unleaded gasoline for aircraft. The two organizations have set a goal to develop an American Standard for Testing and Material (ASTM) specification for unleaded gasoline for aircraft by 1995 and the goal of eliminating the use of leaded gasoline in aircraft by 1998.²⁴⁰

Although Section 211(n) of the CAA does not require a lead phase-down of aviation fuels, the aircraft fuel industry is currently developing standards for unleaded aviation gasoline, but continues to rely on leaded fuels.

7.1.2 Unleaded Fuels

Refiners began producing unleaded gasoline in the early 1970s for automobiles equipped with catalytic converters. As a result of the 1990 CAA amendments, lead additives in gasoline were replaced by high-octane hydrocarbon fractions with properties suitable for gasoline blending. Straight-run refinery products, for example, have comparatively low-octane numbers. On the other hand, aromatics, isoparaffins, and olefins produced from catalytic cracking and reforming processes have much higher octane numbers. Adjusting the relative amount of these hydrocarbon fractions results in gasolines with different octane numbers.²⁴¹ Still, a trace amount of lead remains in unleaded gasoline. This lead is picked up as it passes through refinery processes and fuel distribution systems that had previously contained leaded gasoline. These trace amounts may not exceed 0.05 grams of lead per gallon. At this level, catalytic control devices are still protected.²³¹

7.2 EVAPORATIVE EMISSIONS FROM FUEL DISTRIBUTION FOR MOBILE SOURCES

Calculated TML evaporative profiles are two orders of magnitude greater than TEL profiles because the vapor pressure of TML (23 mm Hg at 68°F) is two orders of magnitude higher than that of TEL (0.2 mm Hg at 68°F). The difference between TML and TEL varies relative to ambient temperatures, with lower temperatures producing the greatest differences.

The TML weight fraction can be applied to leaded gasoline throughput to estimate TML emissions. The TML emission factor can be adjusted for different ambient temperatures, as noted in the following equation:

$$\text{TML}_{\text{gas}} = \frac{1.321 \times 10^{0.60} - \left(\frac{1289.8}{T + 219} \right) + \left(\frac{900}{T + 233} \right)}{6900 + 1.015 \times 10^{0.60} - \left(\frac{1289.8}{T + 219} \right) + \left(\frac{900}{T + 233} \right)}$$

where: TML_{gas} = TML vapor phase fraction (mass TML emitted/mass leaded gasoline throughput)
 T = Temperature ($^{\circ}\text{C}$)

Similarly, the TEL weight fraction can be applied to leaded gasoline throughput to estimate TEL emissions. To adjust TEL emission factors for different ambient temperatures, the following equation can be used:

$$\text{TEL}_{\text{gas}} = \frac{1.934 \times 10^{1.451} - \left(\frac{1789.6}{T + 195} \right) + \left(\frac{900}{T + 233} \right)}{6200 + 1.563 \times 10^{1.451} - \left(\frac{1789.6}{T + 195} \right) + \left(\frac{900}{T + 233} \right)}$$

where: TEL_{gas} = TEL vapor phase fraction (mass TEL emitted/mass leaded gasoline throughput)
 T = Temperature ($^{\circ}\text{C}$)

TEL emissions from the distribution of aviation fuel can be estimated using the following equation:

$$\text{TEL}_{\text{avgas}} = \frac{79.25 \times 10^{0.914} - \left(\frac{1789.6}{T + 195} \right) + \left(\frac{1115.86}{T + 228} \right)}{6900 - 62.35 \times 10^{0.914} - \left(\frac{1789.6}{T + 195} \right) + \left(\frac{1115.86}{T + 228} \right)}$$

where: TEL_{avgas} = TEL vapor phase fraction (mass TEL emitted/mass leaded aviation gasoline throughput)
 T = Temperature ($^{\circ}C$)

In general, most TEL and TML evaporative emissions from leaded fuel distribution are relatively small. In 1990, 5 percent of highway fuel sold in the United States was leaded. Given that the lead concentration of leaded fuel used in the EPA study (0.85 g/gal), and the lead concentrations in current unleaded fuels (0.0003 g/gal) are approximately three orders of magnitude different, and given that the quantity of fuel distributed is approximately two orders of magnitude different, total evaporative emissions from fuel distribution should be less for unleaded than for leaded fuel. By the end of 1995, the lead content of all motor vehicle fuels will be reduced to zero, making the highway fuel distribution category a negligible source.

7.3 COMBUSTION EMISSIONS

Vehicles designed and operated on leaded gasoline exhaust 75 percent of the lead in the fuel. For catalytically equipped vehicles operating on unleaded gasoline, 40 percent of the lead burned is emitted into the atmosphere. Lead is retained in the catalyst (45 percent), crankcase oil (25 percent), combustion chamber, and the rest of the exhaust system (30 percent).^{242,243}

This information can be used to approximate lead emissions from mobile combustion sources using the following equation:

$$E_{cf} = L_f \times \frac{R_f}{100} \times F_f$$

where: E_{cf} = Emission of lead from vehicle combustion for leaded or unleaded fuel “f” (g/year)
 L_f = Lead content of fuel “f” (g/gal)
 R_f = Amount of lead released for fuel type “f” (75 percent for vehicles designed for, and using, leaded gasoline, and 40 percent for vehicles designed for, and using, unleaded gasoline)
 F_f = Fuel throughput (gal/year)

For a more precise estimate of mobile combustion emissions, use of the EPA/ Office of Mobile Sources (OMS) PART5 Mobile Emission Model is recommended. The reader is cautioned that modeling results are only estimates, not actual emissions, and have the potential for being over or under estimated.

Presently, there are no emission factors to characterize lead emissions from aircraft fuel combustion. The equation used to characterize motor vehicle emissions may be used, but will probably lead to an underestimation of emissions because of differences in engine design, exhaust system configurations, and operation.

7.4 ROAD DUST

Several studies have shown that lead from atmospheric deposition can be reintrained by vehicles as road dust.²⁴⁴⁻²⁴⁸ This section provides estimation procedures for this source derived from a U.S. EPA report entitled *Estimating and Controlling Fugitive Lead Emissions from Industrial Sources*.²⁴⁹

7.4.1 Paved Roads

Open dust fugitive emissions from paved roads depend upon the loose surface material and traffic characteristics of the road. These emissions have been determined to vary directly in proportion to the surface material loading and silt content of the road. The surface material loading is the amount of loose dust on the road surface and is measured in units of mass of material per unit area. (Surface material loading for a specific road is typically expressed in units of mass per unit length of road.) The silt content is the percentage of silt (i.e., particles less than or equal to 75 microns in diameter) in the loose surface dust. Some typical values for silt loading on industrial paved roads are presented in Table 7-4. Other factors that affect industrial paved road fugitive emissions include the volume of traffic, number of traffic lanes, average vehicle weight, and the degree to which vehicles travel on nearby unpaved areas (thereby allowing more dust to be deposited on the paved road). This last factor is known as the industrial

TABLE 7-4. INDUSTRIAL PAVED ROAD SILT LOADINGS

Industry	No. of sites ^a	No. of samples ^a	Silt, percent w/w		No. of travel lanes	Silt loading, g/m ²	
			Range	Mean		Range	Mean
Copper smelting	1	3	15.4 - 21.7	19.0	2	188 - 400	292
Iron and steel production	6	20	1.1 - 35.7	12.5	2	0.09 - 79	12
Asphalt batching	1	3	2.6 - 4.6	3.3	1	76 - 193	120
Concrete batching	1	3	5.2 - 6.0	5.5	2	11 - 12	12
Sand and gravel processing	1	3	6.4 - 7.9	7.1	1	53 - 95	70

Source: Reference 249.

^a The data presented in this table are based on an EPA-sponsored sampling and analysis program, for which the number of samples specified in the table were collected at the specified number of sites.

augmentation factor and ranges in value from 1.0 to 7.0. Higher values indicate greater fugitive dust emissions. Typical values for this factor are found in Table 7-5.

The magnitude of fugitive lead emissions (or emissions of any other substance) may be estimated by direct proportion with the percent by weight of lead (or substance of concern) in the silt fraction. Because of variations from location to location, site-specific data should be used for all of the above-mentioned factors whenever possible.

The fugitive lead emission factor for industrial paved roads in units of kilograms per vehicle kilometer traveled (kg/VKT), or pounds per vehicle mile traveled (lb/VMT), can be determined by the following modified equation for total suspended particulate emissions:

$$E = 0.22 I \left(\frac{C}{100} \right) \left(\frac{4}{n} \right) \left(\frac{s}{10} \right) \left(\frac{L}{280} \right) \left(\frac{W}{2.7} \right)^{0.7} \text{ (kg/VKT)}$$

$$E = 0.22 I \left(\frac{C}{100} \right) \left(\frac{4}{n} \right) \left(\frac{s}{10} \right) \left(\frac{L}{1,000} \right) \left(\frac{W}{3} \right)^{0.7} \text{ (lb/VMT)}$$

TABLE 7-5. TYPICAL VALUES FOR PAVED ROAD INDUSTRIAL AUGMENTATION FACTOR (I)

I ^a	Conditions
1.0	Travel on paved roads only
3.5	Travel on paved roads with unpaved shoulders--20 percent of vehicles travel with one set of wheels on shoulder
7.0	Traffic enters from unpaved roads

Source: Reference 249.

^a Values are dimensionless.

where:

E	=	emission factor, kg/VKT (lb/VMT)
I	=	industrial augmentation factor (dimensionless)
C	=	average percent by weight of lead in the silt fraction
n	=	number of traffic lanes
s	=	average surface material silt content, percent
L	=	average surface dust loading, kg/km (lb/mile)
W	=	average vehicle weight, Mg (ton)

To estimate lead emissions from paved road dust, the developed emission factors should be applied to local VMT data.

7.4.2 Unpaved Roads

Fugitive dust emissions from unpaved roads, like paved road fugitive emissions, are directly proportional to the silt content of the surface material. In addition, fugitive lead emissions can be estimated by direct proportion with the lead content in the silt fraction. Unpaved road fugitive dust emissions are also proportional to the mean vehicle speed, mean vehicle weight, and mean number of wheels. Fugitive emissions from unpaved roads are also affected by the rainfall frequency. For particles under 30 microns in diameter, a particle size multiplier must also be included in the computation of emissions. However, for total suspended particulate emissions, which is the concern here, the value of this factor is assumed to be unity, and it may be dropped from the equation.

The fugitive lead emission factor for unpaved roads per unit of vehicle distance traveled can be estimated by the following modified equation for total suspended particulates:

$$E = (1.7) \left(\frac{C}{100} \right) \left(\frac{s}{12} \right) \left(\frac{S}{48} \right) \left(\frac{W}{2.7} \right)^{0.7} \left(\frac{w}{4} \right)^{0.5} \frac{(365 - p)}{365} \text{ (kg/VKT)}$$

$$E = (5.9) \left(\frac{C}{100} \right) \left(\frac{s}{12} \right) \left(\frac{S}{30} \right) \left(\frac{W}{3} \right)^{0.7} \left(\frac{w}{4} \right)^{0.5} \frac{(365 - p)}{365} \text{ (lb/VMT)}$$

where:

E	=	emission factor, kg/VKT (lb/VMT)
C	=	percent by weight of lead in the silt fraction
s	=	average silt content of road surface material, percent
S	=	average vehicle speed, km/h (mil/h)
W	=	average vehicle weight, Mg (ton)
w	=	average number of wheels (dimensionless)
p	=	number of days with ≥ 0.254 mm (0.01 in) of precipitation per year

Measured silt values for a number of industries are given in Table 7-6. The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. As with paved road fugitive dust emission factors, the use of site-specific data is strongly encouraged.

To estimate lead emissions from unpaved road dust, the developed emission factors should be applied to local VMT data.

TABLE 7-6. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIAL ON INDUSTRIAL AND RURAL UNPAVED ROADS

Industry	Road Use or Surface Material	Plant Sites ^a	Test Samples ^a	Silt, percent by weight	
				Range	Mean
Copper smelting	Plant road	1	3	15.9 - 19.1	17.0
Iron and steel production	Plant road	9	20	4.0 - 16.0	8.0
Sand and gravel processing	Plant road	1	3	4.1 - 6.0	4.8
Stone quarrying and processing	Plant road	1	5	10.5 - 15.6	14.1
Taconite mining and processing	Haul road	1	12	3.7 - 9.7	5.8
	Service road	1	8	2.4 - 7.1	4.3
Western surface coal mining	Access road	2	2	4.9 - 5.3	5.1
	Haul road	3	21	2.8 - 18	8.4
	Scraper road	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
Rural roads	Gravel	1	1	N/A	5.0
	Dirt	2	5	5.8 - 68	28.5
	Crushed limestone	2	8	7.7 - 13	9.6

Source: Reference 249.

^a The data presented in this table are based on an EPA-sponsored sampling and analysis program, for which the number of samples specified in this table were collected at the specified number of sites.

N/A = Not applicable.

SECTION 8.0

SOURCE TEST PROCEDURES

The EPA has published reference methods for measuring lead in ambient air and lead contained in stack gas emissions. *EPA Reference Method for the Determination of Lead in Suspended Particulate Matter Collected from Ambient Air* was first published in the *Federal Register* on October 5, 1978, and was last revised on July 1, 1987.²⁵⁰ The EPA has also published Method 12 and draft Method 29 for measuring lead in stack gases. Method 12 was first published in the *Federal Register* on January 14, 1980 and last revised on November 14, 1990 and is used to sample for only total inorganic lead in stack gases.²⁵¹ Draft Method 29 was first published in the *Federal Register* on July 17, 1991 as part of the boiler and industrial furnace regulations and is used to sample for total inorganic and organic lead and other metals in stack gases. EPA Method 29 was finalized on April 25, 1996 and is included in Appendix A of 40 CFR Part 60.

Sections 8.1 and 8.2 of this report summarize the field sampling procedures for measuring lead in ambient air and stack gases, respectively. Section 8.3 describes the different analytical techniques used to analyze and measure the amount of lead collected in ambient air and stack gas samples.

8.1 AMBIENT AIR SAMPLING METHODS

Ambient air concentrations of lead in suspended PM can be measured using *EPA Reference Method for the Determination of Lead in Suspended Particulate Matter Collected from Ambient Air*.²⁵⁰ Figure 8-1 shows a simplified diagram of the components of the high-volume ambient air sampling equipment for lead. The equipment is mounted in an enclosed

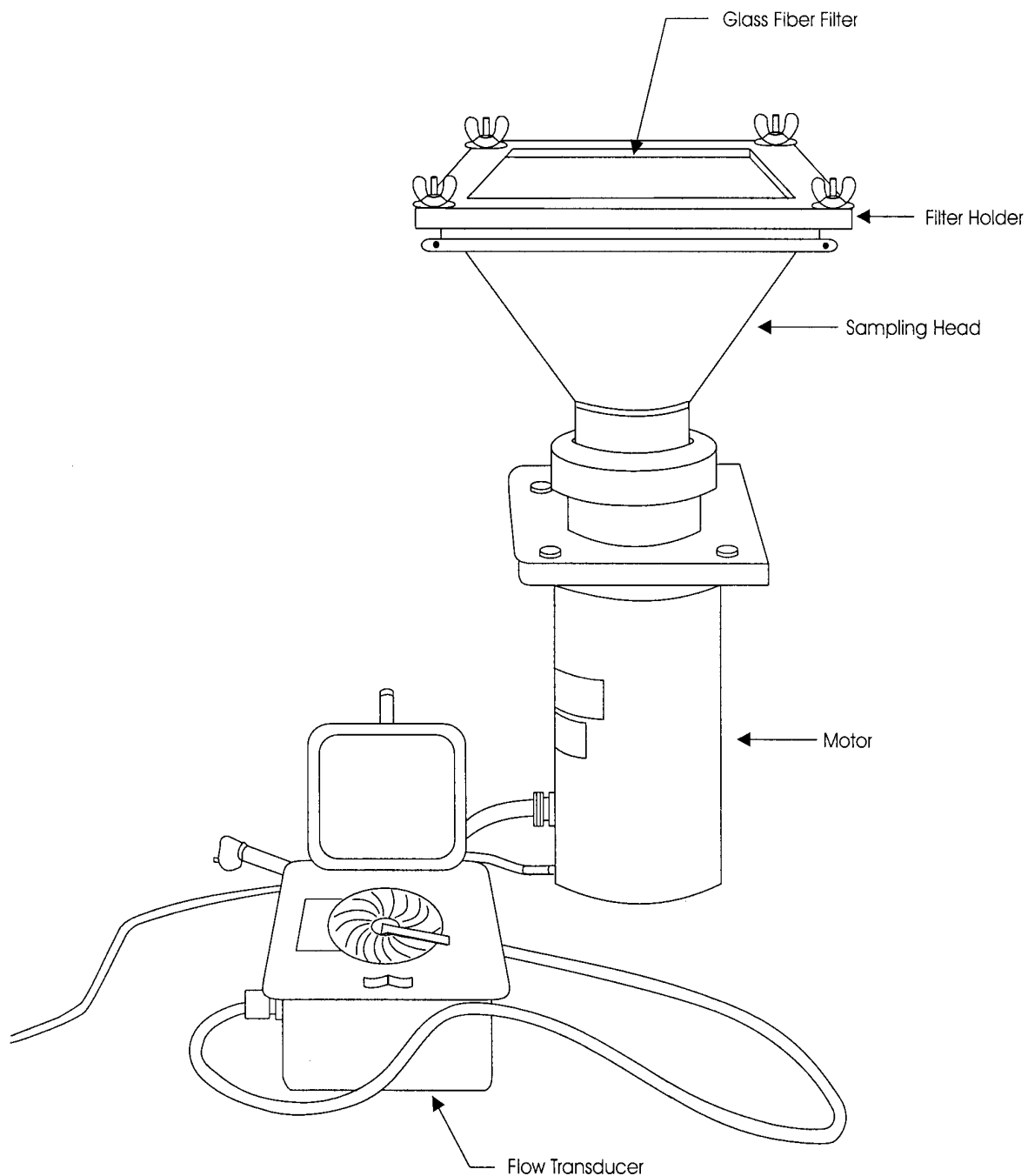


Figure 8-1. Components of a High-Volume Ambient Air Sampler for Lead

Source: Reference 253.

shelter equipped with a roof. Ambient air is drawn under the roof of the shelter through a pre-weighed glass-fiber filter. Figure 8-2 shows a simplified diagram of the air flow through a high-volume sampler located in a shelter.²⁵³ The high-volume sampler should be operated for 24 hours at an average flow rate of 1.7 cubic meters per minute (m^3/min). The primary and secondary national ambient air quality standards for lead are 1.5 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) averaged over a calendar quarter. For determining compliance with the primary and secondary national ambient air quality standards for lead, at least one 24-hour sample must be collected every six days except during periods or seasons exempted by the Regional EPA Administrator.²⁵⁴

After sampling, the filter is removed and sent to a laboratory for analysis. The filter is weighed several times until a constant weight is measured and then the filter is digested in an acid solution and analyzed for total lead content either by atomic absorption spectrophotometry (AAS) or inductively coupled plasma emission spectroscopy (ICP). The typical range in the amount of lead collected by use of this method is 0.07 to 7.5 $\mu\text{g}/\text{m}^3$ assuming an upper linear range of analysis of 15 micrograms per milliliter ($\mu\text{g}/\text{mL}$) and an air volume of 2,400 cubic meters (m^3).

The major advantage to the high-volume lead sampling method is the low detection limit that can be achieved (i.e., 0.07 to 7.5 $\mu\text{g}/\text{m}^3$). Another advantage is that the ambient air sample is collected over a 24-hour period, which encompasses all types of weather conditions, particularly temperature changes, and the range of emission source activities that occur throughout a 24-hour period.

One disadvantage of the high-volume sampling method is that it was designed for sampling only total inorganic lead compounds in suspended PM. Inorganic lead cannot be speciated and most organic lead compounds cannot be detected. A second disadvantage is that the high-volume method is very dependent on meteorological conditions. Any change in wind speed or direction and any amount of precipitation can influence the sample results. To interpret the effects of weather conditions on the sample results, meteorological data must be recorded during the sampling period.

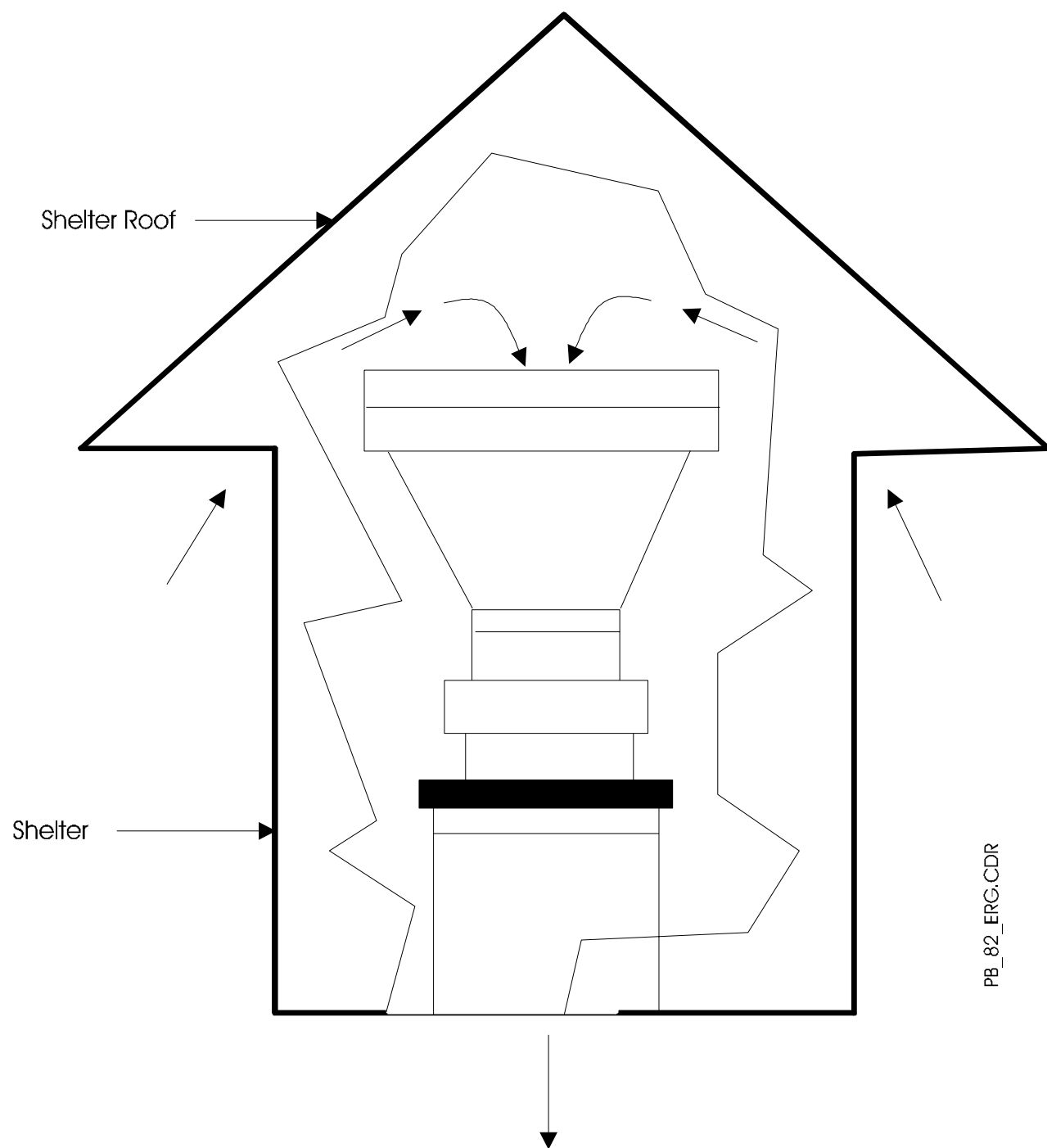


Figure 8-2. Air Flow through a High-Volume Sampler in a Shelter

Source: Reference 253.

8.2 STATIONARY SOURCE SAMPLING METHODS

Two methods are available for sampling stack gas concentrations of lead: EPA Method 12 and EPA Method 29.^{251,252} Method 12 is used to sample for only total inorganic lead. EPA Method 29 is used to sample for total inorganic and organic lead and other metals in a stack. These two methods are described on the following pages.

8.2.1 EPA Method 12 - Methodology for the Determination of Metals Emissions in Exhaust Gases from Hazardous Waste Incineration and Similar Combustion Sources

Method 12 (also called a multi-metals train) can be used to sample PM and total inorganic lead (i.e., elemental lead and inorganic lead compounds) isokinetically from stack gases. A diagram of the Method 12 sampling train is shown in Figure 8-3. Particulate lead is collected through a glass nozzle and probe onto a glass-fiber filter and in a dilute nitric acid solution in the impingers. The nozzle and probe are washed with dilute nitric acid and the wash, filter, and impinger solution are sent to a laboratory, where they are digested in an acid solution and analyzed for total lead content by AAS or ICP.

The exact run time and volume samples vary from source to source depending on the required detection limit. Typically, Method 12 sampling is conducted for 2 hours to sample approximately 2.55 m³ of stack gas. The lower range of detection for this method is 25 µg of total lead. The upper range can be extended considerably by diluting the sample prior to analysis.

The major advantage to Method 12 is that the method was designed to sample for inorganic lead compounds from a wide variety of industrial processes, and the method has been validated. The stack gas stream is sampled isokinetically, which provides an accurate emission rate. Method 12 is also extremely flexible. The length of sample runs and the sample volume collected can be adjusted depending on the expected concentration of the stack gas stream. The disadvantage is that Method 12 cannot be used to speciate inorganic lead compounds or to sample for organic lead compounds.

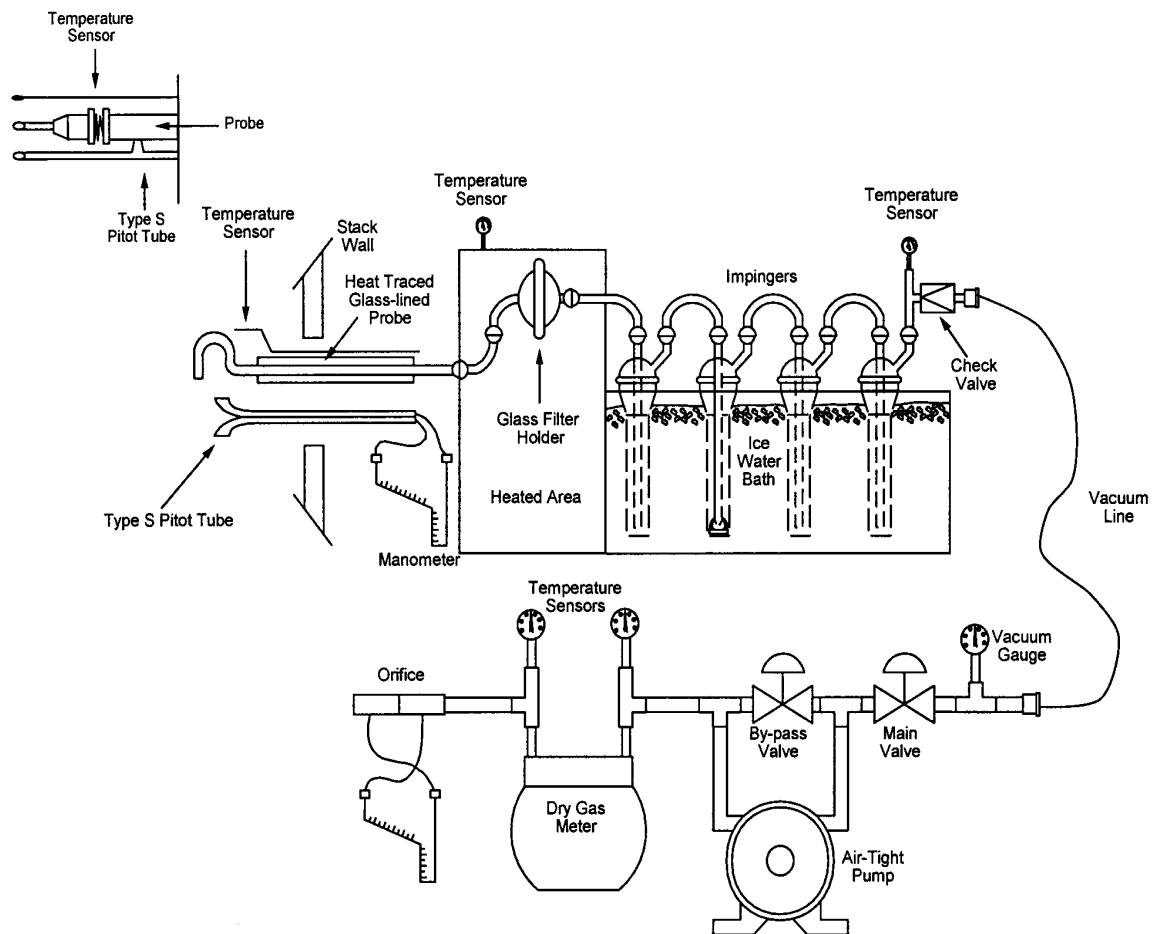


Figure 8-3. Method 12 Sampling Train

Source: Reference 251.

8.2.2 EPA Method 29 - Determination of Metals Emissions from Stationary Sources

EPA Method 29 can be used to sample PM and total inorganic and organic lead compounds isokinetically from stack gases. The Method 29 sampling train is a modified EPA reference Method 5 sampling train and is shown in Figure 8-4.

Particulate lead with a particle size diameter greater than or equal to 0.3 micrometers is collected through a glass nozzle and probe onto a pre-weighed glass-fiber filter. Particulate lead with a particle size diameter less than 0.3 micrometers and lead compounds in the vapor phase pass through the filter and are collected in a dilute nitric acid/hydrogen peroxide solution in the impingers. The nozzle and probe are washed with dilute nitric acid and the wash, filter, and impinger solution are sent to a laboratory, where they are digested in an acid solution and analyzed for lead content either by AAS or ICP. The samples collected on the filter and in the impinger solution can be analyzed separately to differentiate between the amount of particulate lead and lead in the gas phase.

The exact run time and volume sampled varies from source to source depending on the required detection limit. Typically, the Method 29 train is run for 2 hours and samples approximately 2.55 m³ of stack gas. The lower range of detection for this method is 25 µg of total lead. The upper range can be extended considerably by diluting the sample prior to analysis.

This method is applicable to the determination of antimony (sb), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), manganese (Mn), Mercury (Hg), nickel (Ni), phosphorous (P), selenium (Se), silver (Ag), thallium (Ti), and zinc (Zn). Although it is the preferred method for sampling stack gas streams and can measure several metals at one time, the method cannot be used to speciate inorganic or organic lead compounds.

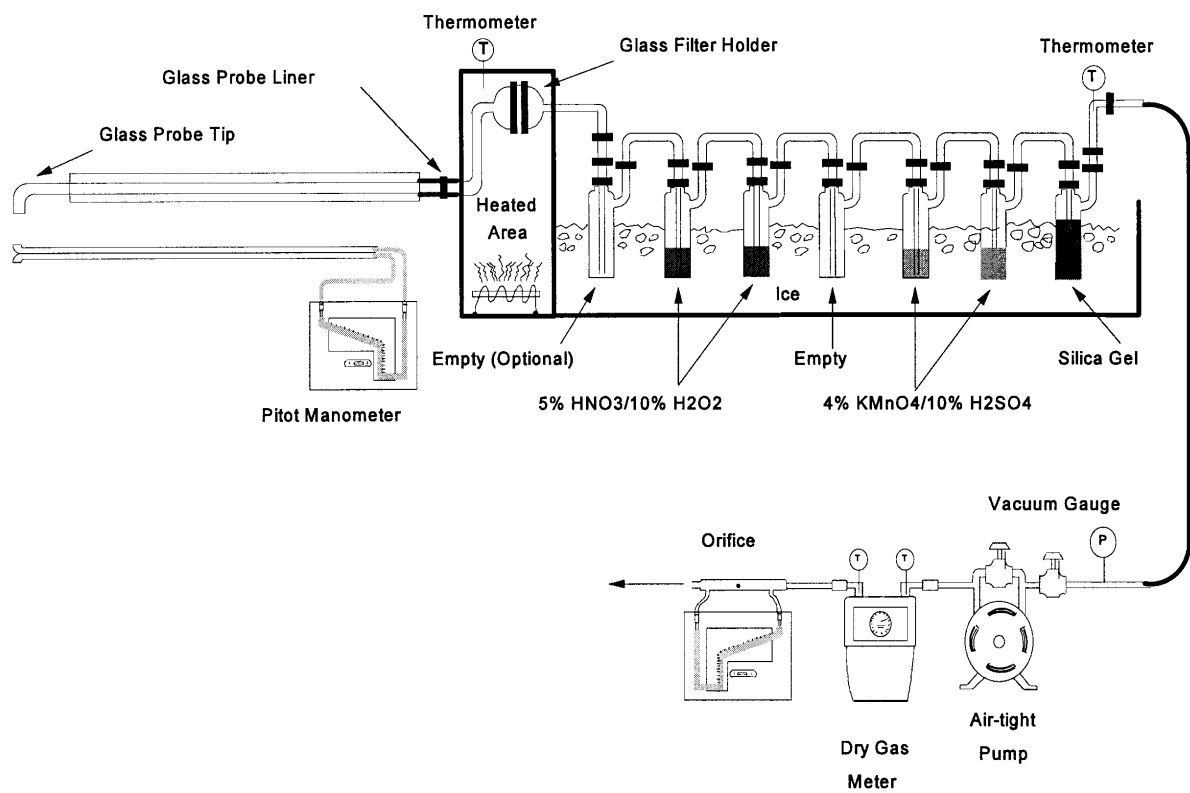


Figure 8-4. Method 29 Sampling Train

Source: Reference 252.

8.3 ANALYTICAL TECHNIQUES FOR THE MEASUREMENT OF LEAD

The most common technique for measuring total lead in air samples is spectroscopy. The two spectroscopic techniques used most by environmental laboratories are AAS and ICP. AAS is the most common method used to measure total lead. The advantages to AAS are that the method is simple, rapid, and applicable to a large number of metals. Samples other than drinking water must be acid-digested prior to analysis. Two types of AAS methods for measuring total lead are direct aspiration (flame) and graphite furnace.

The second most common technique for measuring total lead in air samples is ICP, which allows simultaneous, or sequential, determination of several metals in a sample during a single analytical measurement. Air samples must be acid-digested prior to analysis.

8.3.1 Direct Aspiration (Flame) Atomic Absorption Spectroscopy

Method 7420 specifies the procedure for analyzing air samples for total lead using direct-aspiration (flame) AAS.²⁵⁶ In direct-aspiration (flame) AAS, a sample is aspirated and atomized in an air/acetylene flame. A light beam from a hollow cathode lamp whose cathode is made of the element being measured is directed through the flame into a monochromator, and onto a detector that measures the amount of light absorbed. Absorption depends upon the presence of free, unexcited ground-state atoms in the flame. Because the wavelength of the light beam is characteristic of only the element being measured, the light energy absorbed by the flame is a measure of the concentration of that element in the sample. The detection limit for lead is 100 micrograms per liter ($\mu\text{g/L}$). The optimum concentration ranges are from 1,000 to 20,000 μg per sample. If direct-aspiration (flame) AAS techniques do not provide adequate sensitivity, graphite furnace techniques can be used.

8.3.2 Graphite Furnace Atomic Absorption Spectroscopy

Method 7421 specifies the procedure for analyzing air samples for total lead using graphite furnace AAS.²⁵⁷ The principle of graphite furnace AAS is essentially the same as for direct-aspiration (flame) AAS, except a furnace rather than a flame is used to atomize the sample. In graphite furnace AAS, a representative aliquot of a sample is placed in a graphite tube in the furnace, evaporated to dryness, charred, and atomized. The radiation from a given excited element is passed through the vapor containing ground-state atoms of that element. The intensity of the transmitted radiation decreases in proportion to the amount of the ground-state element in the vapor. The metal's atoms to be measured are placed in the beam of radiation by increasing the temperature of the furnace, thereby causing the injected specimen to be volatilized. A monochromator isolates the characteristic radiation from the hollow cathode lamp or electrodeless discharge lamp, and a photosensitive device measures the attenuated transmitted radiation. The detection limit for lead is 1.0 µg/L. The optimum concentration ranges are from 5 to 100 µg per sample.

The major advantage of this technique is that it affords extremely low detection limits. It is the easiest technique to perform on relatively clean samples. Because this technique is so sensitive, however, interferences can be a problem; finding the optimum combination of digestion, heating times, temperatures, and matrix modifiers can be difficult for complex matrices.

8.3.3 Inductively Coupled Plasma Atomic Emission Spectroscopy

Method 6010A specifies the procedures for analyzing air samples for total lead using ICP.²⁵⁸ The ICP method measures element-emitted light by optical spectrometry. The sample is nebulized and the resulting aerosol is transported to the plasma torch, where excitation occurs. Characteristic atomic-line emission spectra are produced by radio-frequency inductively coupled plasma. The spectra are dispersed by a grating spectrometer, and the intensities of the lines are monitored by photomultiplier tubes. The photocurrents from the photomultiplier tubes

are processed and controlled by a computer. The detection limit for lead is 42 µg/L. The optimum concentration range varies with the make and model of the instrument used.

The primary advantage of ICP is that it allows simultaneous or rapid sequential determination of many elements in a short time. The primary disadvantage is background radiation from other elements and the plasma gases. Although all ICP instruments utilize high-resolution optics and background correction to minimize these interferences, analysis for traces of metals in the presence of a large excess of a single metal is difficult.

SECTION 9.0

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APPENDIX A

EMISSION FACTOR SUMMARY TABLE

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
3-03-010-02	Primary Lead Smelting	Blast Furnace	None	1.0x10 ⁻⁴ lb/ton (5.0x10 ⁻⁵ kg/Mg)	U
			Baghouse	6.7x10 ⁻² lb/ton (3.4x10 ⁻² kg/Mg)	E
			Spray Tower/FF	1.7x10 ⁻² lb/ton (8.5x10 ⁻³ kg/Mg)	U
3-03-010-04	Primary Lead Smelting	Ore Crushing	None	3.0x10 ⁻¹ lb/ton (1.5x10 ⁻¹ kg/Mg)	U
			Baghouse	2.0x10 ⁻³ lb/ton (1.0x10 ⁻³ kg/Mg)	E
3-03-010-25	Primary Lead Smelting	Sinter Machine Leakage	ESP/Scrubber	3.2x10 ⁻² lb/ton (1.6x10 ⁻² kg/Mg)	E
3-03-010-28	Primary Lead Smelting	Tetrahedrite Drier	Baghouse	6.0x10 ⁻⁴ lb/ton (3.0x10 ⁻⁴ kg/Mg)	E
3-03-010-29	Primary Lead Smelting	Sinter Machine (weak gas)	ESP/Scrubber	1.9x10 ⁻² lb/ton (9.5x10 ⁻³ kg/Mg)	E
3-03-010-32	Primary Lead Smelting	Ore Screening	Baghouse	2.0x10 ⁻³ lb/ton (1.0x10 ⁻³ kg/Mg)	E
3-04-004-03	Secondary Lead Smelting	Blast Furnace (Cupola)	None	1.04x10 ² lb/ton (5.2x10 ¹ kg/Mg)	C
			Wet Scrubber/FF/ Cyclone/Settling Chamber/Demister	2.9x10 ⁻¹ (1.5x10 ⁻¹)	C
3-04-004-04	Secondary Lead Smelting	Rotary Sweating Furnace	None	---	E
			Baghouse	2.8x10 ⁻² lb/ton (1.4x10 ⁻² kg/Mg)	D

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
3-04-004-04	Secondary Lead Smelting (continued)		Baghouse/scrubber	1.9x10 ⁻² lb/ton (9.5x10 ⁻³ kg/Mg)	D
3-04-004-13	Secondary Lead Smelting	Smelting Furnace Fugitives	None	---	E
			Baghouse	1.2x10 ⁻² lb/ton (6.0x10 ⁻³ kg/Mg)	U
3-04-004-02	Secondary Lead Smelting	Reverberatory Furnace	None	6.5x10 ¹ lb/ton (3.3x10 ⁻¹ kg/Mg)	C
3-04-004-26	Secondary Lead Smelting	Kettle Refining	None	1.0x10 ⁻² lb/ton (6.0x10 ⁻³ kg/Mg)	C
3-04-004-14	Secondary Lead Smelting	Kettle Refining Fugitives	None	6.00x10 ⁻⁴ lb/ton (3.00x10 ⁻⁴ kg/Mg)	E
			Afterburner/FF/ Venturi Scrubber/ Demister	2.4 lb/ton (1.2 kg/Mg)	
3-04-004-09	Secondary Lead Smelting	Casting	None	1.0x10 ⁻² lb/ton (5.0x10 ⁻³ kg/Mg)	C
3-04-004-25	Secondary Lead Smelting	Casting Fugitives	None	7.0x10 ⁻⁴ lb/ton (3.5x10 ⁻⁴ kg/Mg)	E
3-03-005-03	Primary Copper Smelting Facilities	Converter	None	2.70x10 ⁻¹ lb/ton (0.135 kg/Mg)	C
3-04-002-42	Secondary Copper Smelting Facilities	Reverberatory Furnace [charge with other alloy (7%)]	None	5.0 lb/ton (2.5 kg/Mg)	B
3-04-002-43	Secondary Copper Smelting Facilities	Reverberatory Furnace [charge with high lead (58%)]	None	5.0x10 ¹ lb/ton (2.5x10 ¹ kg/Mg)	B
3-04-002-44	Secondary Copper Smelting Facilities	Reverberatory Furnace (charge with red/yellow brass)	None	1.32x10 ¹ lb/ton (6.6 kg/Mg)	B
3-04-002-xx	Secondary Copper Smelting Facilities	Secondary Copper - smelting	Baghouse	1.00x10 ⁻³ lb/ton (5.00x10 ⁻⁴ kg/Mg)	B

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
3-04-001-09	Secondary Aluminum Production	Burning/Drying	Venturi Scrubber	4.36x10 ⁻³ lb/ton (2.18x10 ⁻³ kg/Mg)	U
			Baghouse	1.04x10 ⁻⁵ lb/ton (5.18x10 ⁻⁶ kg/Mg)	U
			Multiple Cyclones	2.16x10 ⁻² lb/ton (1.08x10 ⁻² kg/Mg)	U
3-04-001-14	Secondary Aluminum Production	Reverberatory Furnace	Baghouse	1.4x10 ⁻³ lb/ton (7.0x10 ⁻⁴ kg/Mg)	D
3-04-003-01	Iron and Steel Foundries	Iron Foundry - Cupola	None	---	B
			Afterburner/ Venturi Scrubber	1.56x10 ⁻³ lb/ton (7.80x10 ⁻⁴ kg/Mg)	U
			Baghouse	2.67x10 ⁻³ lb/ton (1.34x10 ⁻³ kg/Mg)	U
3-04-003-02	Iron and Steel Foundries	Iron Foundry - Reverberatory Furnace	None	---	B
3-04-003-03	Iron and Steel Foundries	Iron Foundry - Electric Induction Furnace	None	---	B
3-04-003-20	Iron and Steel Foundries	Iron Foundry - Casting	Afterburner/ Venturi Scrubber	4.80x10 ⁻³ lb/ton (2.40x10 ⁻³ kg/Mg)	U
3-03-031-01	Leadbearing Ore Crushing & Grinding	Lead Ore (5.1% Pb content)	None	3.00x10 ⁻¹ lb/ton (1.50x10 ⁻¹ kg/Mg)	B
3-03-031-02	Leadbearing Ore Crushing & Grinding	Zinc Ore (0.2% Pb content)	None	1.20x10 ⁻² lb/ton (6.00x10 ⁻³ kg/Mg)	B
3-03-031-03	Leadbearing Ore Crushing & Grinding	Copper Ore (0.2% Pb content)	None	1.20x10 ⁻² lb/ton (6.00x10 ⁻³ kg/Mg)	B
3-03-031-04	Leadbearing Ore Crushing & Grinding	Lead-Zinc Ore (2.0% Pb content)	None	1.20x10 ⁻¹ lb/ton (6.00x10 ⁻² kg/Mg)	B

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
3-03-031-05	Leadbearing Ore Crushing & Grinding	Copper-Lead Ore (2.0% Pb content)	None	1.20x10 ⁻¹ lb/ton (6.00x10 ⁻² kg/Mg)	B
3-03-031-06	Leadbearing Ore Crushing & Grinding	Copper-Zinc Ore (0.2% Pb content)	None	1.20x10 ⁻² lb/ton (6.00x10 ⁻³ kg/Mg)	B
3-03-031-07	Leadbearing Ore Crushing & Grinding	Copper-Lead-Zinc Ore (2.0% Pb content)	None	1.20x10 ⁻¹ lb/ton (6.00x10 ⁻² kg/Mg)	B
A21-04- 002-000	Residential Coal Combustion	Bituminous/ Subbituminous Coal - All Combustor Types	None	2.00x10 ⁻² lb/ton (1.00x10 ⁻² kg/Mg)	U
A21-04- 001-000	Residential Coal Combustion	Anthracite Coal - All Combustor Types	None	1.60x10 ⁻² lb/ton (8.00x10 ⁻³ kg/Mg)	U
A21-04- 004-000	Residential Distillate Oil-fired Furnaces	Distillate (No. 2 oil) Oil-fired Furnaces	None	2.2x10 ⁻⁴ lb/MMBtu (9.5x10 ⁻¹⁴ kg/Joule)	U
1-01-009-01	Wood Waste-fired Utility Boilers	Wood Waste-fired Boiler (Bark-fired)	None	2.90x10 ⁻³ lb/ton (1.45x10 ⁻³ kg/Mg)	D
A-4	1-01-009-02	Wood Waste-fired Boiler (Wood/Bark-fired)	ESP	1.60x10 ⁻⁵ lb/ton (8.00x10 ⁻⁶ kg/Mg)	D
			Scrubber	3.50x10 ⁻⁴ lb/ton (1.75x10 ⁻⁴ kg/Mg)	D
			Multiple Cyclone with/without Flyash Reinjection	3.20x10 ⁻⁴ lb/ton (1.60x10 ⁻⁴ kg/Mg)	D
1-01-009-03	Wood Waste-fired Utility Boilers	Wood Waste-fired Boiler (Wood-fired)	ESP	1.10x10 ⁻³ lb/ton (5.50x10 ⁻⁴ kg/Mg)	D
			Multiple Cyclone without Flyash Reinjection	3.10x10 ⁻⁴ lb/ton (1.55x10 ⁻⁴ kg/Mg)	D
			None	2.9x10 ⁻³ lb/ton (1.45x10 ⁻³ kg/Mg)	U

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
1-01-009-03	Wood Waste-fired Utility Boilers (continued)		Limestone Injection, Thermal de-NO _x with Ammonia Injection, Water Treatment, Multi-Cyclone, Fabric Collector	4.49x10 ⁻⁶ lb/MMBtu ^b (1.93x10 ⁻¹⁵ kg/Joule)	U
1-02-009-01	Wood Waste-fired Industrial Boilers	Wood Waste-fired Boiler (Bark-fired, >50,000 lb steam)	ESP - Medium Efficiency	1.50x10 ⁻⁶ lb/MMBtu (6.46x10 ⁻¹⁶ kg/Joule)	U
			None	2.90x10 ⁻³ lb/ton (1.45x10 ⁻³ kg/Mg)	D
1-02-009-02	Wood Waste-fired Industrial Boilers	Wood Waste-fired Boiler (Wood/Bark-fired, >50,000 lb steam)	Multiple Cyclone with Flyash Reinjection	3.20x10 ⁻⁴ lb/ton (1.60x10 ⁻⁴ kg/Mg)	D
			ESP	1.60x10 ⁻⁵ lb/ton (8.00x10 ⁻⁶ kg/Mg)	D
			Scrubber	3.50x10 ⁻⁴ lb/ton (1.75x10 ⁻⁴ kg/Mg)	D
			Multiple Cyclone without Flyash Reinjection	3.20x10 ⁻⁴ lb/ton (1.60x10 ⁻⁴ kg/Mg)	D
1-02-009-03	Wood Waste-fired Industrial Boilers	Wood Waste-fired Boiler (Wood-fired, >50,000 lb steam)	Wet Scrubber - Medium Efficiency	1.60x10 ⁻⁵ lb/MMBtu (6.89x10 ⁻¹⁵ kg/Joule)	U
			Multiple Cyclone without Flyash Reinjection/Wet Scrubber - Medium Efficiency	4.00x10 ⁻⁵ lb/MMBtu (1.72x10 ⁻¹⁴ kg/Joule)	U
			Multiple Cyclone without Flyash Reinjection	3.10x10 ⁻⁴ lb/ton (1.55x10 ⁻⁴ kg/Mg)	D
			ESP	1.10x10 ⁻³ lb/ton (5.50x10 ⁻⁴ kg/Mg)	D

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
1-02-009-03 (continued)	Wood Waste-fired Industrial Boilers	Wood Waste-fired Boiler (Wood-fired, >50,000 lb steam)	Multiple Cyclone without Flyash Reinjection/ESP - Medium Efficiency	2.25x10 ⁻⁶ lb/MMBtu (9.70x10 ⁻¹⁶ kg/Joule)	U
1-02-009-04	Wood Waste-fired Industrial Boilers	Wood Waste-fired Boiler (Bark-fired, <50,000 lb steam)	None	2.90x10 ⁻³ lb/ton (1.45x10 ⁻³ kg/Mg)	D
1-02-009-05	Wood Waste-fired Industrial Boilers	Wood Waste-fired Boiler (Wood/Bark-fired, <50,000 lb steam)	Multiple Cyclone with Flyash Reinjection	3.20x10 ⁻⁴ lb/ton (1.60x10 ⁻⁴ kg/Mg)	D
			ESP	1.60x10 ⁻⁵ lb/ton (8.00x10 ⁻⁶ kg/Mg)	D
			Scrubber	3.50x10 ⁻⁴ lb/ton (1.75x10 ⁻⁴ kg/Mg)	D
			Multiple Cyclone without Flash Reinjection	3.20x10 ⁻⁴ lb/ton (1.60x10 ⁻⁴ kg/Mg)	D
1-02-009-06	Wood Waste-fired Industrial Boilers	Wood Waste-fired Boiler (Wood-fired, <50,000 lb steam)	Multiple Cyclone without Flyash Reinjection	3.10x10 ⁻⁴ lb/ton (1.55x10 ⁻⁴ kg/Mg)	D
			ESP	1.10x10 ⁻³ lb/ton (5.50x10 ⁻⁴ kg/Mg)	D
			Scrubber	1.14x10 ⁻⁵ lb/MMBtu (4.91x10 ⁻¹⁵ kg/Joule)	U
1-03-009-01	Wood Waste-fired Comm/Instit. Boilers	Wood/Bark-fired Boiler (Bark- fired)	None	2.90x10 ⁻³ lb/ton (1.45x10 ⁻³ kg/Mg)	D
1-01-006-04	Natural Gas Utility Boiler	Natural Gas Boilers	Overfire Air and Flue Gas Recirculation	2.71x10 ⁻⁴ lb/ton	E
1-01-006-04	Gas-fired Utility Boiler	Gas Fired Boiler	None	.37 lb/trillion BTU	U
1-03-009-02	Wood Waste-fired Comm/Instit. Boilers	Wood/Bark-fired Boiler (Wood/Bark-fired)	Multiple Cyclone with Flyash Reinjection	3.20x10 ⁻⁴ lb/ton (1.60x10 ⁻⁴ kg/Mg)	D

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
1-03-009-02	Wood Waste-fired Comm/Instit. Boilers (continued)		Scrubber	3.50x10 ⁻⁴ lb/ton (1.75x10 ⁻⁴ kg/Mg)	D
			ESP	1.60x10 ⁻⁵ lb/ton (8.00x10 ⁻⁶ kg/Mg)	D
			Multiple Cyclone without Flyash Reinjection	3.20x10 ⁻⁴ lb/ton (1.60x10 ⁻⁴ kg/Mg)	D
1-03-009-03	Wood Waste-fired Comm/Instit. Boilers	Wood/Bark-fired Boiler (Wood-fired)	Multiple Cyclone without Flyash Reinjection	3.10x10 ⁻⁴ lb/ton (1.55x10 ⁻⁴ kg/Mg)	D
			ESP	1.10x10 ⁻³ lb/ton (5.50x10 ⁻⁴ kg/Mg)	D
1-01-001-02	Coal-fired Utility Boilers	Anthracite Coal Travelling Grate Overfeed Stoker	None	8.90x10 ⁻³ lb/ton (4.45x10 ⁻³ kg/Mg)	E
1-01-002-01	Coal-fired Utility Boilers	Bituminous Coal: Pulverized: Wet Bottom	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-01-002-02	Coal-fired Utility Boilers	Bituminous Coal: Pulverized: Dry Bottom	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
			ESP,FF or venturi scrubber	4.20x10 ⁻⁴ (lb/ton) 2.10x10 ⁻⁴ kg/Mg)	A
1-01-002-03	Coal-fired Utility Boilers	Bituminous Coal: Cyclone Furnace	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
			ESP,FF or venturi scrubber	4.20x10 ⁻⁴ (lb/ton) 2.10x10 ⁻⁴ kg/Mg)	A
1-01-002-04	Coal-fired Utility Boilers	Bituminous Coal: Spreader Stoker	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-01-002-05	Coal-fired Utility Boilers	Bituminous Coal: Travelling Grate (Overfeed) Stoker	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
1-01-002-21	Coal-fired Utility Boilers	Subbituminous Coal: Pulverized: Wet Bottom	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-01-002-22	Coal-fired Utility Boilers	Subbituminous Coal: Pulverized: Dry Bottom	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
			ESP,FF or venturi scrubber	4.20x10 ⁻⁴ (lb/ton) 2.10x10 ⁻⁴ kg/Mg)	A
1-01-002-23	Coal-fired Utility Boilers	Subbituminous Coal: Cyclone Furnace	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
			ESP,FF or venturi scrubber	4.20x10 ⁻⁴ (lb/ton) 2.10x10 ⁻⁴ kg/Mg)	A
1-01-002-24	Coal-fired Utility Boilers	Subbituminous Coal: Spreader Stoker	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-01-002-25	Coal-fired Utility Boilers	Subbituminous Coal: Travelling Grate (Overfeed) Stoker	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
	Coal-fired Utility Boilers	Coal-fired Unit	PM	4.8 lb/trillion BTU	U
	Coal-fired Utility Boilers	Coal-fired Unit	PM/SO ²	5.8 lb/trillion BTU	U
1-02-001-04	Coal-fired Industrial Boilers	Anthracite Coal Travelling Grate (Overfeed) Stoker	None	8.90x10 ⁻³ lb/ton (4.45x10 ⁻³ kg/Mg)	E
1-02-002-01	Coal-fired Industrial Boilers	Bituminous Coal Pulverized: Wet Bottom	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-02-002-02	Coal-fired Industrial Boilers	Bituminous Coal Pulverized Coal: Dry Bottom	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
			ESP,FF or venturi scrubber	4.20x10 ⁻⁴ (lb/ton) 2.10x10 ⁻⁴ kg/Mg)	A
1-02-002-03	Coal-fired Industrial Boilers	Bituminous Coal Cyclone Furnace	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
1-02-002-03	Coal-fired Industrial Boilers (continued)		ESP,FF or venturi scrubber	4.20x10 ⁻⁴ (lb/ton) 2.10x10 ⁻⁴ kg/Mg	A
1-02-002-04	Coal-fired Industrial Boilers	Bituminous Coal Spreader Stoker	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-02-002-05	Coal-fired Industrial Boilers	Bituminous Coal Overfeed Stoker	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-02-002-06	Coal-fired Industrial Boilers	Bituminous Coal Underfeed Stoker	None	2.24x10 ⁻¹ lb/ton (1.12x10 ⁻¹ kg/Mg)	U
1-02-002-13	Coal-fired Industrial Boilers	Bituminous Coal Wet Slurry	None	9.89x10 ⁻³ lb/ton (4.95x10 ⁻³ kg/Mg)	U
1-01-002-21	Coal-fired Industrial Boilers	Subbituminous Coal: Pulverized: Wet Bottom	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-01-002-22	Coal-fired Industrial Boilers	Subbituminous Coal: Pulverized: Dry Bottom	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
			ESP,FF or venturi scrubber	4.20x10 ⁻⁴ (lb/ton) 2.10x10 ⁻⁴ kg/Mg	A
1-01-002-23	Coal-fired Industrial Boilers	Subbituminous Coal: Cyclone Furnace	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
			ESP,FF or venturi scrubber	4.20x10 ⁻⁴ (lb/ton) 2.10x10 ⁻⁴ kg/Mg	A
1-01-002-24	Coal-fired Industrial Boilers	Subbituminous Coal: Spreader Stoker	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-01-002-25	Coal-fired Industrial Boilers	Subbituminous Coal: Travelling Grate (Overfeed) Stoker	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
1-03-001-02	Coal-fired Comm/Inst. Boilers	Anthracite Coal Travelling Grate (Overfeed) Stoker	None	8.90x10 ⁻³ lb/ton (4.45x10 ⁻³ kg/Mg)	E

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

A-10	SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
	1-03-002-08	Coal-fired Comm/Inst. Boilers	Bituminous Coal Underfeed Stoker	Multiple Cyclone without Flyash Reinjection	1.21×10^{-3} lb/ton (6.05×10^{-4} kg/Mg)	U
	1-03-002-03	Coal-fired Comm/Inst. Boilers	Bituminous Coal Cyclone Furnace	None	5.07×10^{-4} lb/MMBtu (2.18×10^{-13} kg/Joule)	E
				ESP,FF or venturi scrubber	4.20×10^{-4} (lb/ton) 2.10×10^{-4} kg/Mg)	A
	1-03-002-05	Coal-fired Comm/Inst. Boilers	Bituminous Coal Pulverized: Wet Bottom	None	5.07×10^{-4} lb/MMBtu (2.18×10^{-13} kg/Joule)	E
	1-03-002-06	Coal-fired Comm/Inst. Boilers	Bituminous Coal Pulverized Coal: Dry Bottom	None	5.07×10^{-4} lb/MMBtu (2.18×10^{-13} kg/Joule)	E
				ESP,FF or venturi scrubber	4.20×10^{-4} (lb/ton) 2.10×10^{-4} kg/Mg)	A
	1-03-002-07	Coal-fired Comm/Inst. Boilers	Bituminous Coal Overfeed Stoker	None	5.07×10^{-4} lb/MMBtu (2.18×10^{-13} kg/Joule)	E
	1-03-002-09	Coal-fired Comm/Inst. Boilers	Bituminous Coal Spreader Stoker	None	5.07×10^{-4} lb/MMBtu (2.18×10^{-13} kg/Joule)	E
	1-03-002-21	Coal-fired Comm/Inst. Boilers	Subbituminous Coal: Pulverized: Wet Bottom	None	5.07×10^{-4} lb/MMBtu (2.18×10^{-13} kg/Joule)	E
	1-03-002-22	Coal-fired Comm/Inst. Boilers	Subbituminous Coal: Pulverized: Dry Bottom	None	5.07×10^{-4} lb/MMBtu (2.18×10^{-13} kg/Joule)	E
				ESP,FF or venturi scrubber	4.20×10^{-4} (lb/ton) 2.10×10^{-4} kg/Mg)	A
	1-03-002-23	Coal-fired Comm/Inst. Boilers	Subbituminous Coal: Cyclone Furnace	None	5.07×10^{-4} lb/MMBtu (2.18×10^{-13} kg/Joule)	E
				ESP,FF or venturi scrubber	4.20×10^{-4} (lb/ton) 2.10×10^{-4} kg/Mg)	A
	1-03-002-24	Coal-fired Comm/Inst. Boilers	Subbituminous Coal: Spreader Stoker	None	5.07×10^{-4} lb/MMBtu (2.18×10^{-13} kg/Joule)	E

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

A-11	SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
	1-03-002-25	Coal-fired Comm/Inst. Boilers	Subbituminous Coal: Travelling Grate (Overfeed) Stoker	None	5.07x10 ⁻⁴ lb/MMBtu (2.18x10 ⁻¹³ kg/Joule)	E
	1-01-004-01	Oil-fired Utility Boilers	Residual Oil-fired Boiler: No. 6 Oil, Normal Firing	None	1.00x10 ⁻⁵ lb/MMBtu (4.33x10 ⁻¹⁵ kg/Joule)	E
				Flue Gas Recirculation	2.17x10 ⁻⁵ lb/MMBtu (9.35x10 ⁻¹⁵ kg/Joule)	U
	1-01-004-04	Oil-fired Utility Boilers	Residual Oil-fired Boiler: No. 6 Oil, Tangential Firing	None	1.00x10 ⁻⁵ lb/MMBtu (4.33x10 ⁻¹⁵ kg/Joule)	E
	1-01-004-05	Oil-fired Utility Boilers	Residual Oil-fired Boiler: No. 5 Oil, Normal Firing	None	1.60x10 ⁻⁵ lb/MMBtu (6.89x10 ⁻¹⁵ kg/Joule)	U
		Oil-fired Utility Boilers	Oil-fired Units	PM Control	2.6 lb/trillion BTU	U
		Oil-fired Utility Boilers	Oil-fired Units	PM/SO ₂ Control	9.0 lb/trillion BTU	U
	1-01-005-01	Oil-fired Utility Boilers	Distillate Oil Grades 1 and 2 Oil	None	8.90x10 ⁻⁶ lb/MMBtu (3.84x10 ⁻¹⁵ kg/Joule)	E
	1-02-004-01	Oil-fired Industrial Boilers	Residual Oil Grade 6 Oil	None	1.00x10 ⁻⁵ lb/MMBtu (4.33x10 ⁻¹⁵ kg/Joule)	E
	1-02-005-01	Oil-fired Industrial Boilers	Distillate Oil Grades 1 and 2 Oil	None	8.90x10 ⁻⁶ lb/MMBtu (3.84x10 ⁻¹⁵ kg/Joule)	E
	1-03-004-01	Oil-fired Comm/Indust Boilers	Residual Oil Grade 6 Oil	None	1.00x10 ⁻⁵ lb/MMBtu (4.33x10 ⁻¹⁵ kg/Joule)	E
	1-03-005-01	Oil-fired Comm/Indust Boilers	Distillate Oil Grades 1 and 2 Oil	None	8.90x10 ⁻⁶ lb/MMBtu (3.84x10 ⁻¹⁵ kg/Joule)	E
	1-02-013-02	Waste Oil-fired Industrial Boilers	Waste Oil	None	1.68 lb/1000 gal (2.01x10 ⁻¹ kg/kL)	U

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
1-05-001-13	Waste Oil-fired Industrial Boilers	Waste Oil Air Atomized Burner	None	50x L lb/1000 gal (6.0 x L kg/kL)	D
1-01-013-02	Waste Oil-fired Comm/Inst Boilers	Waste Oil	None	1.68 lb/1000 gal (2.01x10 ⁻¹ kg/kL)	U
1-05-002-13	Waste Oil-fired Comm/Inst Boilers	Waste Oil Air Atomized Burner	None	50x L lb/1000 gal (6.0 x L ¹ kg/kL)	D
1-01-012-01	Solid Waste-fired Utility Boilers	Solid Waste	None	2.65x10 ⁻¹ lb/ton (1.33x10 ⁻¹ kg/Mg)	U
			ESP	1.24x10 ⁻⁴ lb/MMBtu (5.34x10 ⁻¹⁴ kg/Joule)	C
			Spray Dryer/Absorber/ESP	<2.66x10 ⁻⁴ lb/ton (<1.33x10 ⁻⁴ kg/Mg)	U
1-02-012-02	Miscellaneous Industrial Boilers	Solid Waste Refuse-derived Fuel	None	1.30x10 ⁻¹ lb/ton (6.50x10 ⁻² kg/Mg)	U
5-01-001-01	Municipal Waste Combustion Sources	Starved-Air: Multiple- Chamber	None	1.20x10 ⁻¹ lb/ton (6.00x10 ⁻² kg/Mg)	U
			ESP	2.82x10 ⁻³ lb/ton (1.41x10 ⁻³ kg/Mg)	C
5-01-001-02	Municipal Waste Combustion Sources	Mass Burn: Single-Chamber	None	1.80x10 ⁻¹ lb/ton (9.00x10 ⁻² kg/Mg)	U
5-01-001-03	Municipal Waste Combustion Sources	Refuse-derived Fuel	None	2.01x10 ⁻¹ lb/ton (1.00x10 ⁻¹ kg/Mg)	C
			ESP	3.66x10 ⁻³ lb/ton (1.83x10 ⁻³ kg/Mg)	A
			Spray Dryer/FF	1.04x10 ⁻³ lb/ton (5.20x10 ⁻⁴ kg/Mg)	D
			Spray Dryer/ESP	1.16x10 ⁻³ lb/ton (5.80x10 ⁻⁴ kg/Mg)	B

¹L = weight percent lead in fuel. Multiply numeric value by L to obtain emission factor.

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
A-13	5-01-001-04 Municipal Waste Combustion Sources	Mass Burn: Refractory Wall Combustor	None	2.13x10 ⁻¹ lb/ton (1.07x10 ⁻¹ kg/Mg)	A
			Spray Dryer/FF	2.61x10 ⁻⁴ lb/ton (1.31x10 ⁻⁴ kg/Mg)	A
			Spray Dryer/ESP	9.15x10 ⁻⁴ lb/ton (4.58x10 ⁻⁴ kg/Mg)	A
			Dry Sorbent Injection/FF	2.97x10 ⁻⁴ lb/ton (1.49x10 ⁻⁴ kg/Mg)	C
			Dry Sorbent Injection/ESP	2.90x10 ⁻³ lb/ton (1.45x10 ⁻³ kg/Mg)	E
			ESP	3.00x10 ⁻³ lb/ton (1.50x10 ⁻³ kg/Mg)	A
	5-01-001-05 Municipal Waste Combustion Sources	Mass Burn: Waterwall Combustor	None	2.13x10 ⁻¹ lb/ton (1.07x10 ⁻¹ kg/Mg)	A
			Spray Dryer/FF	2.61x10 ⁻⁴ lb/ton (1.31x10 ⁻⁴ kg/Mg)	A
			Spray Dryer/ESP	9.15x10 ⁻⁴ lb/ton (4.58x10 ⁻⁴ kg/Mg)	A
			Dry Sorbent Injection/FF	2.97x10 ⁻⁴ lb/ton (1.49x10 ⁻⁴ kg/Mg)	C
			Dry Sorbent Injection/ESP	2.90x10 ⁻³ lb/ton (1.45x10 ⁻³ kg/Mg)	E
			ESP	3.00x10 ⁻³ lb/ton (1.50x10 ⁻³ kg/Mg)	A
	5-01-001-06 Municipal Waste Combustion Sources	Mass Burn: Rotary Waterwall Combustor	None	2.13x10 ⁻¹ lb/ton (1.07x10 ⁻¹ kg/Mg)	A
			Spray Dryer/FF	2.61x10 ⁻⁴ lb/ton (1.31x10 ⁻⁴ kg/Mg)	A

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
5-01-001-06	Municipal Waste Combustion Sources (continued)		Spray Dryer/ESP	9.15x10 ⁻⁴ lb/ton (4.58x10 ⁻⁴ kg/Mg)	A
			Dry Sorbent Injection/FF	2.97x10 ⁻⁴ lb/ton (1.49x10 ⁻⁴ kg/Mg)	C
			Dry Sorbent Injection/ESP	2.90x10 ⁻³ lb/ton (1.45x10 ⁻³ kg/Mg)	E
			ESP	3.00x10 ⁻³ lb/ton (1.50x10 ⁻³ kg/Mg)	A
5-01-001-07	Municipal Waste Combustion Sources	Modular Excess Air Combustor	None	2.13x10 ⁻¹ lb/ton (1.07x10 ⁻¹ kg/Mg)	A
			Spray Dryer/FF	2.61x10 ⁻⁴ lb/ton (1.31x10 ⁻⁴ kg/Mg)	A
			Spray Dryer/ESP	9.15x10 ⁻⁴ lb/ton (4.58x10 ⁻⁴ kg/Mg)	A
			Dry Sorbent Injection/FF	2.97x10 ⁻⁴ lb/ton (1.49x10 ⁻³ kg/Mg)	C
			Dry Sorbent Injection/ESP	2.90x10 ⁻³ lb/ton (1.45x10 ⁻³ kg/Mg)	E
			ESP	3.00x10 ⁻³ lb/ton (1.50x10 ⁻³ kg/Mg)	A
5-01-005-15	Sewage Sludge Incinerator Sources	Multiple-hearth Furnace	None	1.00x10 ⁻¹ lb/ton (5.00x10 ⁻² kg/Mg)	B
			Single Cyclone/Venturi Scrubber	6.00x10 ⁻³ lb/ton (3.00x10 ⁻³ kg/Mg)	E
			Single Cyclone	6.00x10 ⁻² lb/ton (3.00x10 ⁻² kg/Mg)	E
			ESP	2.00x10 ⁻³ lb/ton (1.00x10 ⁻³ kg/Mg)	E

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
5-01-005-15	Sewage Sludge Incinerator Sources (continued)		Venturi Scrubber	1.80x10 ⁻³ lb/ton (9.00x10 ⁻⁴ kg/Mg)	E
			Venturi Scrubber/Wet ESP	1.80x10 ⁻⁴ lb/ton (9.00x10 ⁻⁵ kg/Mg)	E
			Venturi Scrubber/ Impingement-type Wet Scrubber	6.00x10 ⁻² lb/ton (3.00x10 ⁻² kg/Mg)	B
			Venturi Scrubber/ Impingement-type Wet Scrubber/Afterburner	1.00x10 ⁻¹ lb/ton (5.00x10 ⁻² kg/Mg)	E
			Impingement-type Wet Scrubber	4.00x10 ⁻² lb/ton (2.0x10 ⁻² kg/Mg)	E
			Single Cyclone/Venturi Scrubber/Impingement Scrubber	2.20x10 ⁻² lb/ton (1.10x10 ⁻² kg/Mg)	E
5-01-005-16	Sewage Sludge Incinerator Sources	Fluidized Bed	None	4.00x10 ⁻² lb/ton (2.00x10 ⁻² kg/Mg)	E
			FF	1.00x10 ⁻⁵ lb/ton (5.00x10 ⁻⁶ kg/Mg)	E
			Impingement-type Wet Scrubber	6.00x10 ⁻³ lb/ton (3.00x10 ⁻³ kg/Mg)	E
			Venturi Scrubber Impingement-type Wet Scrubber	1.60x10 ⁻¹ lb/ton (8.00x10 ⁻² kg/Mg)	E
			Venturi Scrubber/ Impingement-type Wet Scrubber/ESP	2.00x10 ⁻⁶ lb/ton (1.00x10 ⁻⁶ kg/Mg)	E
5-01-005-05	Medical Waste Combustion Sources	Other Incineration Pathological/Rotary Kiln	None	1.24x10 ⁻¹ lb/ton (6.20x10 ⁻² kg/Mg)	E

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
5-01-005-05	Medical Waste Combustion Sources	Other Incineration Pathological/ Controlled Air	None	7.28x10 ⁻² lb/ton (3.64x10 ⁻² kg/Mg)	B
5-01-005-05	Medical Waste Combustion Sources	Other Incineration Pathological	Wet Scrubber - High Efficiency	6.98x10 ⁻² lb/ton (3.49x10 ⁻² kg/Mg)	E
			Wet Scrubber - Medium Efficiency/FF	1.60x10 ⁻³ lb/ton (8.00x10 ⁻⁴ kg/Mg)	E
			FF	9.92x10 ⁻⁵ lb/ton (4.96x10 ⁻⁵ kg/Mg)	E
			Spray Dryer/ FF	1.89x10 ⁻⁴ lb/ton (9.45x10 ⁻⁵ kg/Mg)	E
			Spray Dryer/Carbon Injection/FF	7.38x10 ⁻⁵ lb/ton (3.69x10 ⁻⁵ kg/Mg)	E
			Dry Sorbent Injection/ ESP	4.70x10 ⁻³ lb/ton (2.35x10 ⁻³ kg/Mg)	E
			Dry Sorbent Injection/FF	6.25x10 ⁻⁵ lb/ton (3.12x10 ⁻¹ kg/Mg)	E
			Dry Sorbent Injection/ Carbon Injection/FF	9.27x10 ⁻⁵ lb/ton (4.64x10 ⁻⁵ kg/Mg)	E
			Dry Sorbent Injection/FF/Scrubber	5.17x10 ⁻⁵ lb/ton (2.59x10 ⁻⁵ kg/Mg)	E
			Wet Scrubber - Low Efficiency	7.94x10 ⁻² lb/ton (3.97x10 ⁻² kg/Mg)	E
5-02-005-05	Medical Waste Combustion Sources	Commercial - Incineration - Pathological	None (Rotary Kiln Incinerator)	1.24x10 ⁻¹ lb/ton (6.20x10 ⁻² kg/Mg)	E
			Afterburner	6.50x10 ⁻⁴ lb/ton (3.30x10 ⁻⁴ kg/Mg)	E
			FF	9.92x10 ⁻⁵ lb/ton (4.96x10 ⁻⁵ kg/Mg)	E

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
5-02-005-05	Medical Waste Combustion Sources (continued)		Wet Scrubber - High Efficiency	6.98x10 ⁻² lb/ton (3.49x10 ⁻² kg/Mg)	E
			Wet Scrubber - Medium Efficiency/FF	1.60x10 ⁻³ lb/ton (8.00x10 ⁻⁴ kg/Mg)	E
			Spray Dryer/FF	1.89x10 ⁻⁴ lb/ton (9.45x10 ⁻⁵ kg/Mg)	E
			Spray Dryer/Carbon Injection/FF	7.38x10 ⁻⁵ lb/ton (3.69x10 ⁻⁵ kg/Mg)	E
			Dry Sorbent Injection/ESP	4.70x10 ⁻³ lb/ton (2.35x10 ⁻³ kg/Mg)	E
			Dry Sorbent Injection/Carbon Injection/FF	9.27x10 ⁻⁵ lb/ton (4.64x10 ⁻⁵ kg/Mg)	E
			Dry Sorbent Injection/FF	6.25x10 ⁻⁵ lb/ton (3.12x10 ⁻⁵ kg/Mg)	E
			None (Controlled Air Incinerator)	7.28x10 ⁻² lb/ton (3.64x10 ⁻² kg/Mg)	B
			Dry Sorbent Injection/ FF/Scrubber	5.17x10 ⁻⁵ lb/ton (2.59x10 ⁻⁵ kg/Mg)	E
			Wet Scrubber - Low Efficiency	7.94x10 ⁻² lb/ton (3.97x10 ⁻² kg/Mg)	E
3-09-025-01	Drum and Barrel Reclamation Sources	Drum Reclamation: Drum Burning Furnace	None	3.50x10 ⁻⁴ lb/barrel (1.59x10 ⁻¹ g/barrel)	E
5-03-002-03	Open Burning of Scrap Tires	Open Burning of Shredded Automobile Tires	None	2.00x10 ⁻⁴ lb/ton (1.00x10 ⁻⁴ kg/Mg)	C
		Burning of Chunk Automobile Tires	None	6.70x10 ⁻⁴ lb/ton (3.35x10 ⁻⁴ kg/Mg)	C

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
3-15-021-01	Crematories	Crematory Stack	None	4.10x10 ⁻⁸ lb/body (1.86x10 ⁻⁸ kg/body)	U
3-07-001-04	Kraft Process Recovery Furnaces & Smelt Dissolving Tanks	Direct Contact Evaporator Kraft Recovery Furnace	ESP, ESP/Wet Scrubber	9.5x10 ¹ lb/10 ⁶ ton (4.8x10 ¹ kg/10 ⁶ Mg)	D
3-07-001-10	Kraft Process Recovery Furnaces & Smelt Dissolving Tanks	Nondirect Contact Evaporator Kraft Recovery Furnace	ESP, ESP/Wet Scrubber	1.2x10 ² lb/10 ⁶ ton (5.9x10 ¹ kg/10 ⁶ Mg)	D
3-07-001-05	Kraft Process Recovery Furnaces & Smelt Dissolving Tanks	Smelt Dissolving Tank	Demister, Venturi Scrubber	2.3x10 ¹ lb/10 ⁶ ton (1.2x10 ¹ kg/10 ⁶ Mg)	D
3-07-001-06	Lime Kilns	Lime Kiln	None	1.09x10 ⁻⁴ lb/ton (5.44x10 ⁻⁵ kg/Mg)	U
			Scrubber	1.41x10 ⁴ lb/ton (7.07x10 ³ kg/Mg)	D
3-07-002-22	Sulfite Process Recovery Furnaces	Sulfite Recovery Furnace	None	1.70x10 ¹ lb/10 ⁶ ton (8.5 kg/10 ⁶ Mg)	D
3-05-006-06	Portland Cement Manufacturing	Dry Process Kilns	FF	7.50x10 ⁻⁵ lb/ton (3.75x10 ⁻⁵ kg/Mg)	D
			ESP	7.10x10 ⁻⁴ lb/ton (3.55x10 ⁻⁴ kg/Mg)	D
			None	1.20x10 ⁻¹ lb/ton (6.00x10 ⁻² kg/Mg)	U
3-05-006-13	Portland Cement Manufacturing	Dry Process Raw Material Grinding or Drying	None	4.00x10 ⁻² lb/ton (2.00x10 ⁻² kg/Mg)	U
3-05-006-17	Portland Cement Manufacturing	Dry Process Clinker Grinding	None	4.00x10 ⁻² lb/ton (2.00x10 ⁻² kg/Mg)	U
3-05-006-22	Portland Cement Manufacturing	Dry Process Preheater Kilns	FF	7.50x10 ⁻⁵ lb/ton (3.75x10 ⁻⁵ kg/Mg)	D

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
3-05-006-22	Portland Cement Manufacturing (continued)		ESP	7.10x10 ⁻⁴ lb/ton (3.55x10 ⁻⁴ kg/Mg)	D
3-05-006-23	Portland Cement Manufacturing	Dry Process Preheater/ Precalculator Kiln	FF	7.50x10 ⁻⁵ lb/ton (3.75x10 ⁻⁵ kg/Mg)	D
			ESP	7.10x10 ⁻⁴ lb/ton (3.55x10 ⁻⁴ kg/Mg)	D
3-05-007-06	Portland Cement Manufacturing	Wet Process Kilns	ESP	7.10x10 ⁻⁴ lb/ton (3.55x10 ⁻⁴ kg/Mg)	D
			FF	7.50x10 ⁻⁵ lb/ton (3.75x10 ⁻⁵ kg/Mg)	D
			None	1.00x10 ⁻¹ lb/ton (5.00x10 ⁻² kg/Mg)	U
3-05-007-17	Portland Cement Manufacturing	Wet Process Clinker Grinding	None	2.00x10 ⁻² lb/ton (1.00x10 ⁻² kg/Mg)	U
3-05-014	Processed and Blown Glass	All Processes	None	5 lb/ton (2.5 kg/Mg)	B
3-04-005-05	Lead-acid Battery Production	Overall Process	None	---	U
3-04-005-06	Lead-acid Battery Production	Grid Casting	None	---	B
			Rotoclone	6.73x10 ⁻² lb/1000 batteries (3.06x10 ⁻² kg/1000 batteries)	U
3-04-005-07	Lead-acid Battery Production	Paste Mixing	None	---	B
			Wet Scrubber - Medium Efficiency	4.00x10 ⁻⁴ lb/1000 batteries (2.00x10 ⁻⁴ kg/1000 batteries)	U
3-04-005-08	Lead-acid Battery Production	Lead Oxide Mill (Baghouse Outlet)	FF	---	C

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
3-04-005-09	Lead-acid Battery Production	Three-process Operation	None	---	B
			FF	3.77x10 ⁻¹ lb/1000 batteries (1.71x10 ⁻¹ kg/1000 batteries)	U
3-04-005-10	Lead-acid Battery Production	Lead Reclaiming Furnace	None	---	B
			Scrubber	1.01x10 ⁻¹ lb/1000 batteries (5.05x10 ⁻² kg/1000 batteries)	U
3-04-005-11	Lead-acid Battery Production	Small Parts Casting	None	1.00x10 ⁻¹ lb/1000 batteries (4.60x10 ⁻² kg/1000 batteries)	C
3-04-005-12	Lead-acid Battery Production	Formation	None	---	
3-04-040-01	Lead Cable Coating	Cable Covering	None	5.00x10 ⁻¹ lb/ton (2.50x10 ⁻¹ kg/Mg)	C
3-09-060-01	Ceramic/Glaze Application	Ceramic Glaze Spraying - Spray Booth	None	3.0 lb/ton (1.5 kg/Mg)	B
3-04-051-01	Miscellaneous Lead Products	Ammunition	None	<1.0 lb/ton (<5.0x10 ⁻¹ kg/Mg)	C
3-04-051-02	Miscellaneous Lead Products	Bearing Metals	None	Negligible	C
3-04-051-03	Miscellaneous Lead Products	Other Metallic Lead Processes	None	1.5 lb/ton (7.5x10 ⁻¹ kg/Mg)	C
3-05-035-05	Miscellaneous Lead Products	Abrasive Grain Processing/Washing/Drying	Wet Scrubber	4.4x10 ⁻³ lb/ton (2.2x10 ⁻³ kg/Mg)	E
3-06-001-01	Miscellaneous Lead Products	Type Metal Production/ Remelting	Industry Average (Cyclones, FF, ESP, or Wet Scrubber)	2.5x10 ⁻¹ lb/ton (1.3x10 ⁻¹ kg/Mg)	C

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
3-04-004-14	Miscellaneous Lead Products	Lead Melting Pot	Afterburner/ Scrubber	4.6×10^{-2} lb/ton (2.3×10^{-2} kg/Mg)	D
3-05-002-01	Batch-Mix Hot-Mix Asphalt Plants	Rotary Dryer	FF	7.4×10^{-7} lb/ton (3.7×10^{-7} kg/Mg)	D
			Wet Scrubber - Medium Efficiency	3.10×10^{-6} lb/ton (1.55×10^{-6} kg/Mg)	U
			Wet Scrubber - Medium Efficiency/Single Cyclone	1.03×10^{-6} lb/ton (5.15×10^{-7} kg/Mg)	U
			Single Cyclone/Baghouse	2.00×10^{-6} lb/ton (1.00×10^{-6} kg/Mg)	U
			Multiple Cyclone without Fly Ash Reinjection/Baghouse	2.08×10^{-7} lb/ton (1.04×10^{-7} kg/Mg)	U
			None	4.0 lb/ton (2.0 kg/Mg)	U
3-05-002-05	Drum-mix Hot-mix Asphalt Plants	Drum Dryer	FF	3.30×10^{-6} lbs/ton (1.70×10^{-6} kg/Mg)	D
No SCC/AMS code	EOD Activities	TNT	None	4.1×10^{-4} lb emitted/lb treated (4.1×10^{-4} g emitted/g treated)	U
	EOD Activities	Double-based Propellant (DB)	None	1.3×10^{-2} lb emitted/lb treated (1.3×10^{-2} g emitted/g treated)	U
	EOD Activities	Composite-based Propellant (CB)	None	9.4×10^{-5} lb emitted/lb treated (9.4×10^{-5} g emitted/g treated)	U

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES (CONTINUED)

SCC/AMS Code	Description	Emission Source	Control Device	Emission Factor English (Metric)	Factor Rating
	EOD Activities	20-mm High-explosive Incendiary Cartridges	None	1.8×10^{-3} lb emitted/lb treated (1.8×10^{-3} g emitted/g treated)	U
	EOD Activities	40-mm High-explosive Cartridges	None	1.3×10^{-3} lb emitted/lb treated (1.3×10^{-3} g emitted/g treated)	U
	EOD Activities	M18A1 Claymore Antipersonnel Mine	None	5.3×10^{-7} lb emitted/lb treated (5.3×10^{-7} g emitted/g treated)	U
	EOD Activities	T45E7 Adapter-booster	None	7.7×10^{-4} lb emitted/lb treated (7.7×10^{-4} g emitted/g treated)	U
	EOD Activities	PBAN-Ammonium Perchlorate Propellant	None	2.2×10^{-6} lb emitted/lb treated (2.2×10^{-6} g emitted/g treated)	U
	EOD Activities	CTPB-Ammonium Perchlorate Propellant	None	2.3×10^{-6} lb emitted/lb treated (2.3×10^{-6} g emitted/g treated)	U
	EOD Activities	PEG/PBAN	None	1.0×10^{-6} lb emitted/lb treated (1.0×10^{-6} g emitted/g treated)	U

TECHNICAL REPORT DATA*(PLEASE READ INSTRUCTIONS ON THE REVERSE BEFORE COMPLETING)*

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16. ABSTRACT <p>TO ASSIST GROUPS INTERESTED IN INVENTORYING AIR EMISSIONS OF VARIOUS POTENTIALLY TOXIC SUBSTANCES, THE U.S. ENVIRONMENTAL PROTECTION AGENCY IS PREPARING A SERIES OF DOCUMENTS, SUCH AS THIS, TO COMPILE AVAILABLE INFORMATION ON SOURCES AND EMISSIONS OF THESE SUBSTANCES. THIS DOCUMENT DEALS SPECIFICALLY WITH LEAD AND LEAD COMPOUNDS. ITS INTENDED AUDIENCE INCLUDES, FEDERAL, STATE, AND LOCAL AIR POLLUTION PERSONNEL AND OTHERS INTERESTED IN LOCATING POTENTIAL EMITTERS OF LEAD AND IN MAKING GROSS ESTIMATES OF AIR EMISSIONS THEREFROM.</p> <p>THIS DOCUMENT PRESENTS INFORMATION ON (1) THE TYPES OF SOURCES THAT MAY EMIT LEAD; (2) PROCESS VARIATIONS AND RELEASE POINTS FOR THESE SOURCES; AND (3) AVAILABLE EMISSIONS INFORMATION INDICATING THE POTENTIAL FOR LEAD RELEASES INTO THE AIR FROM EACH OPERATION.</p>		
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